

Appendix D

Fault Trees

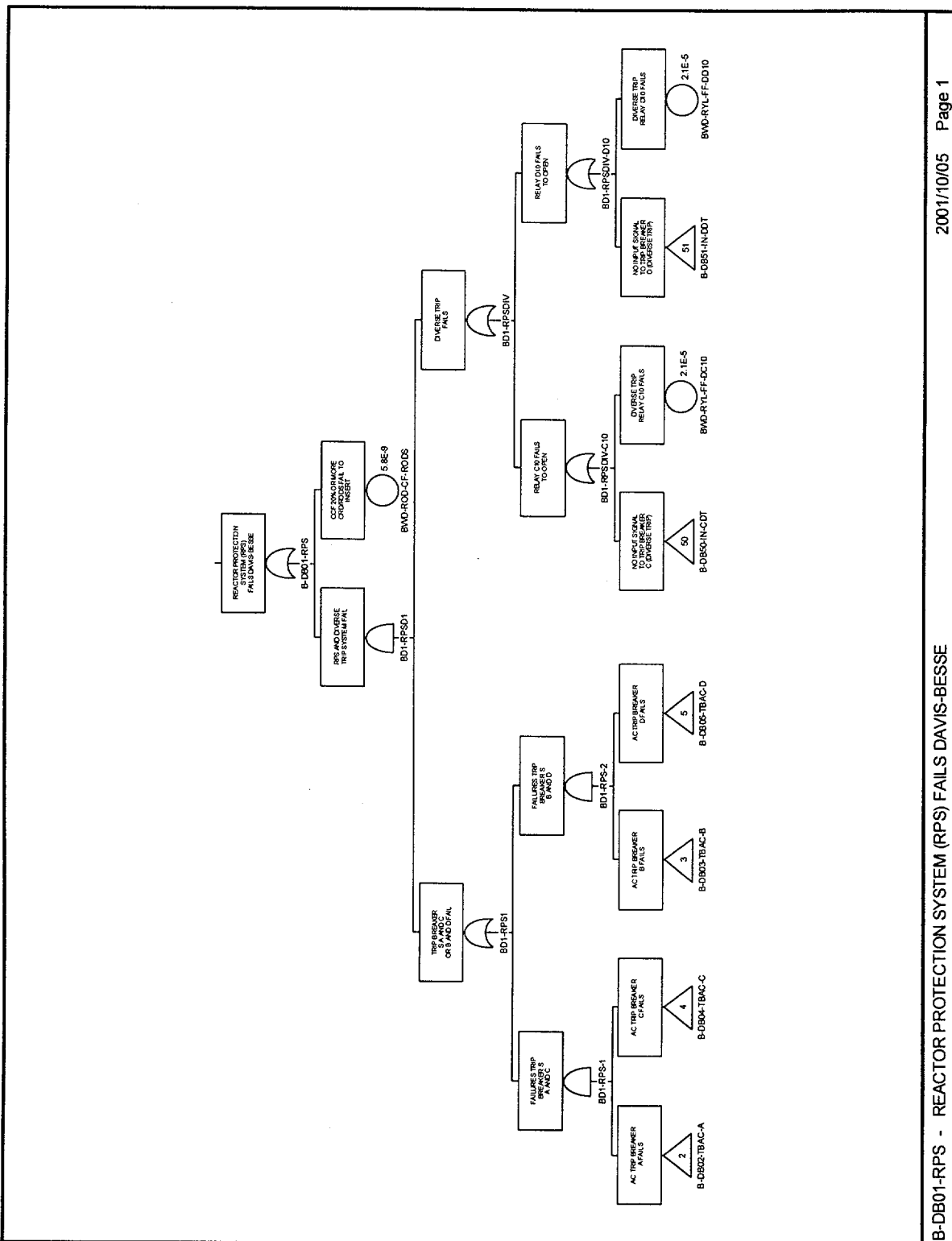
Appendix D

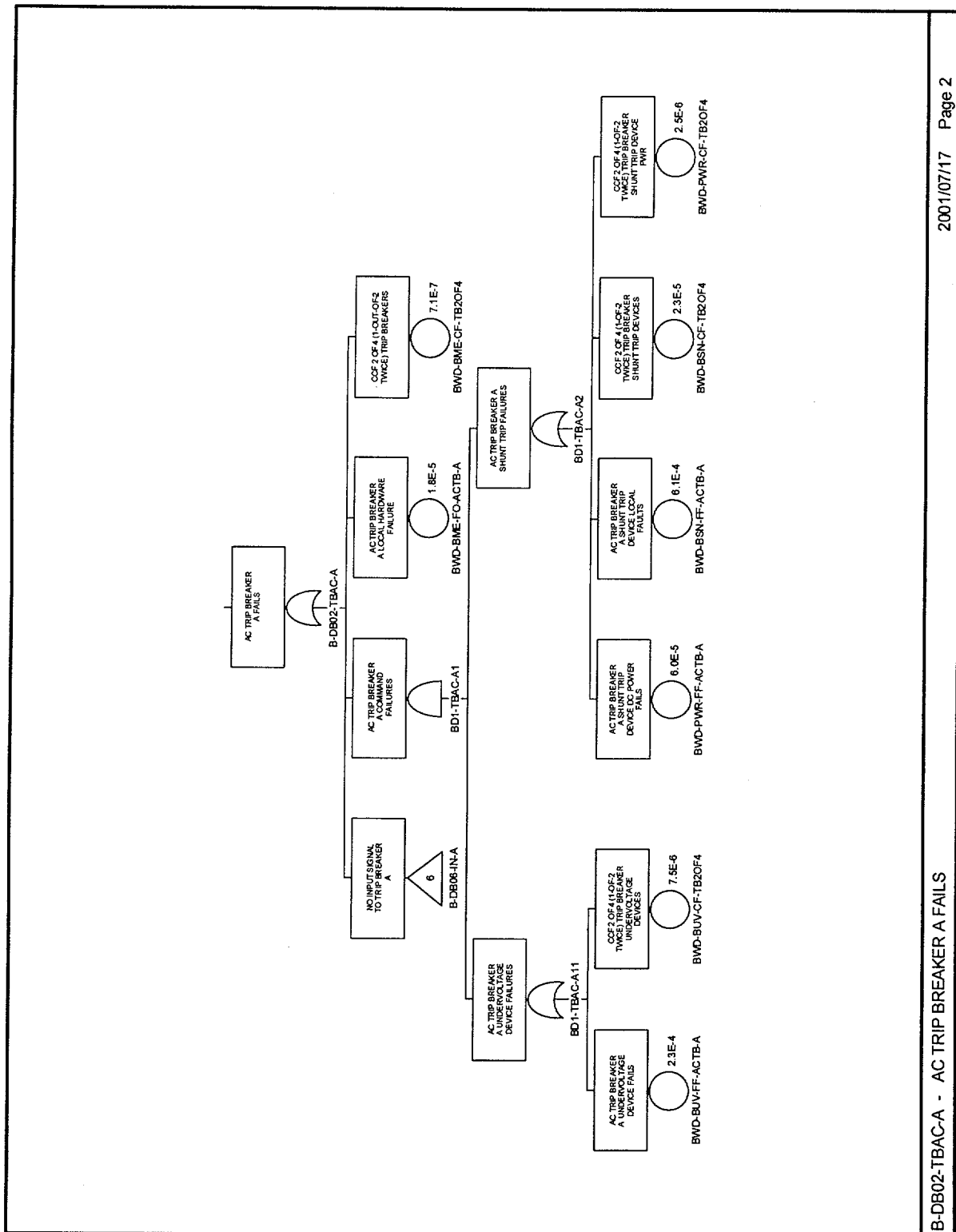
Fault Trees

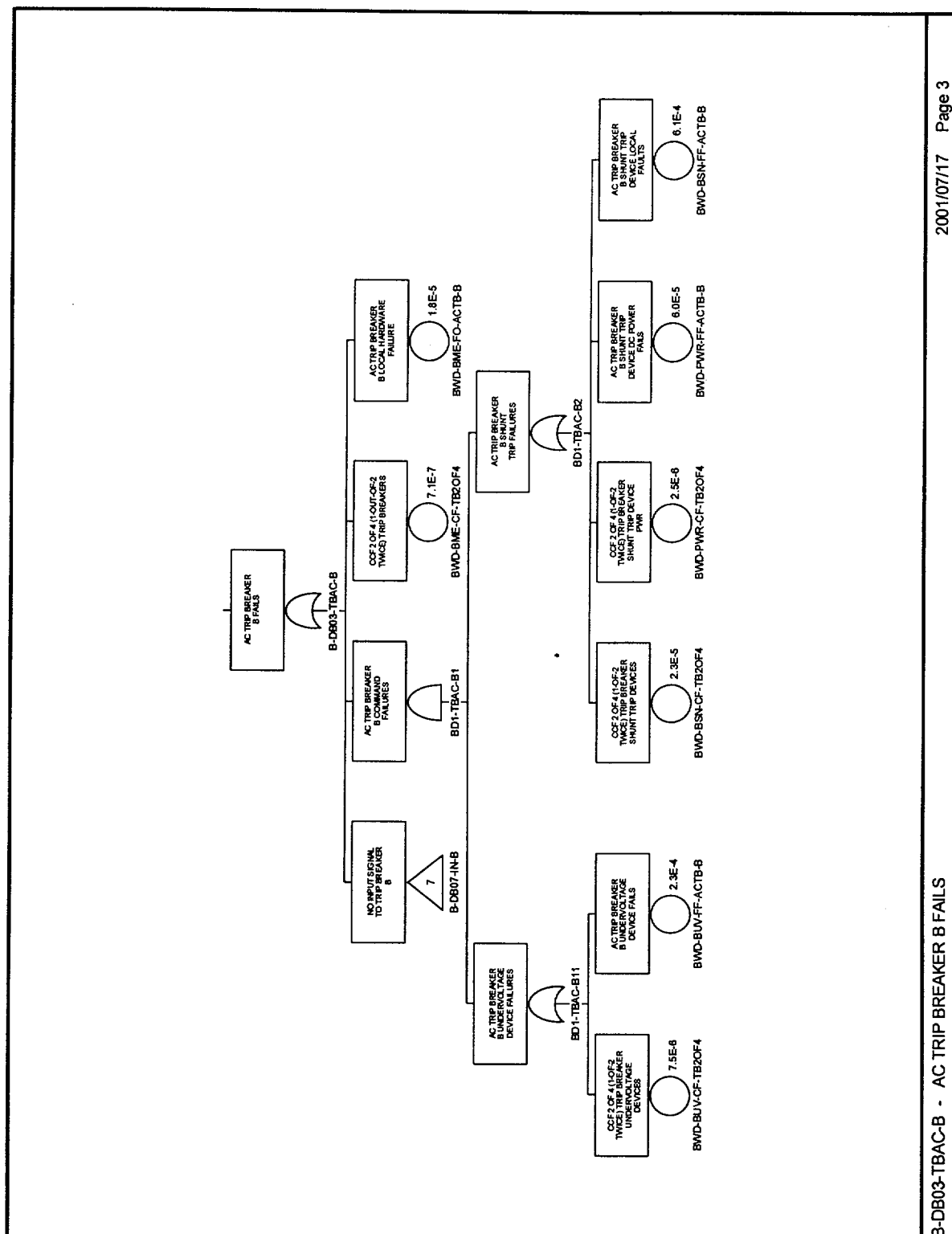
This appendix contains the reactor protection system (RPS) fault trees representing the Babcock & Wilcox RPS designs. The number near the bottom of transfer gates indicates the fault tree page number (shown in the lower right corner of the fault tree border) where the logic is transferred.

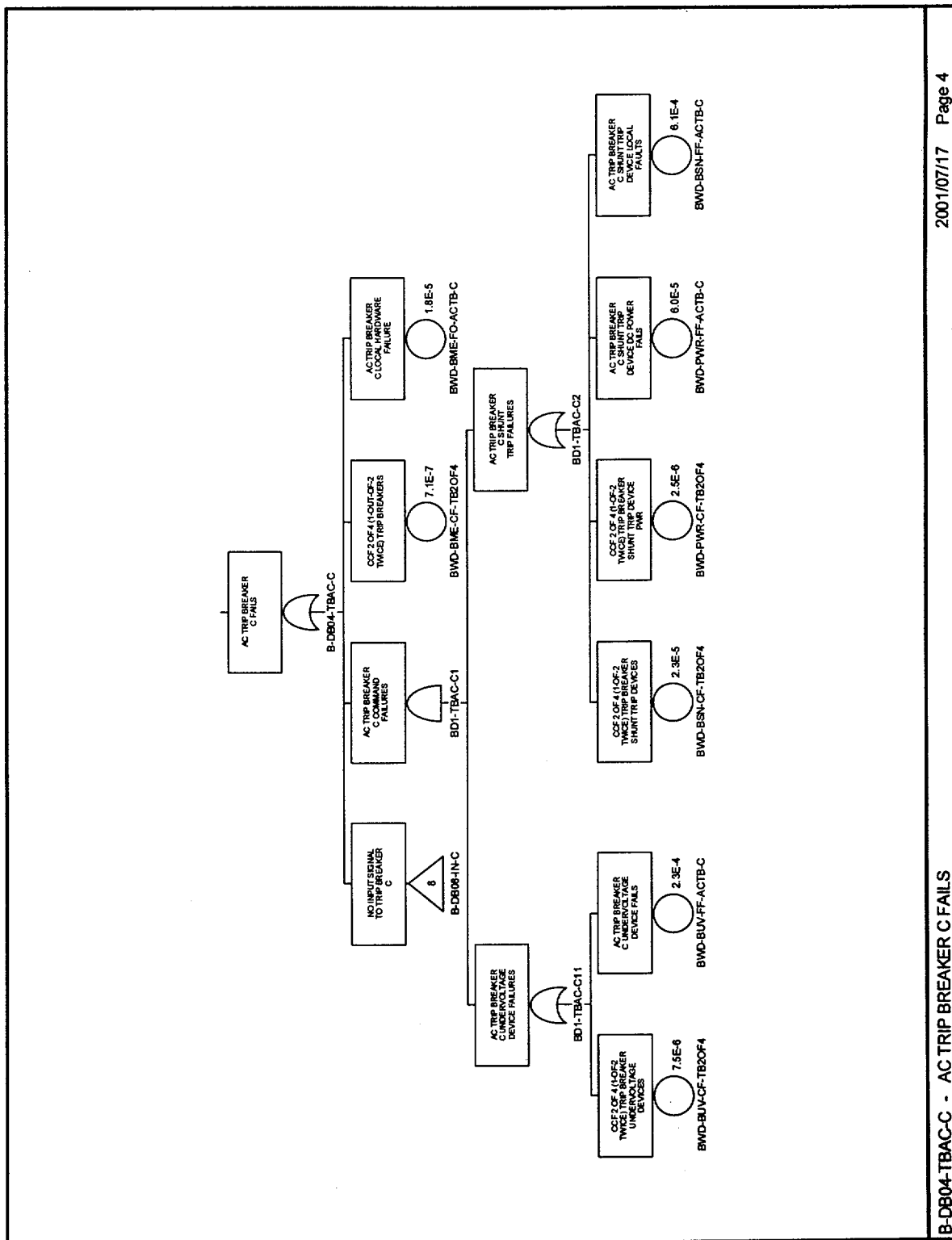
Davis-Besse Model	D-3
Oconee Model	D-69

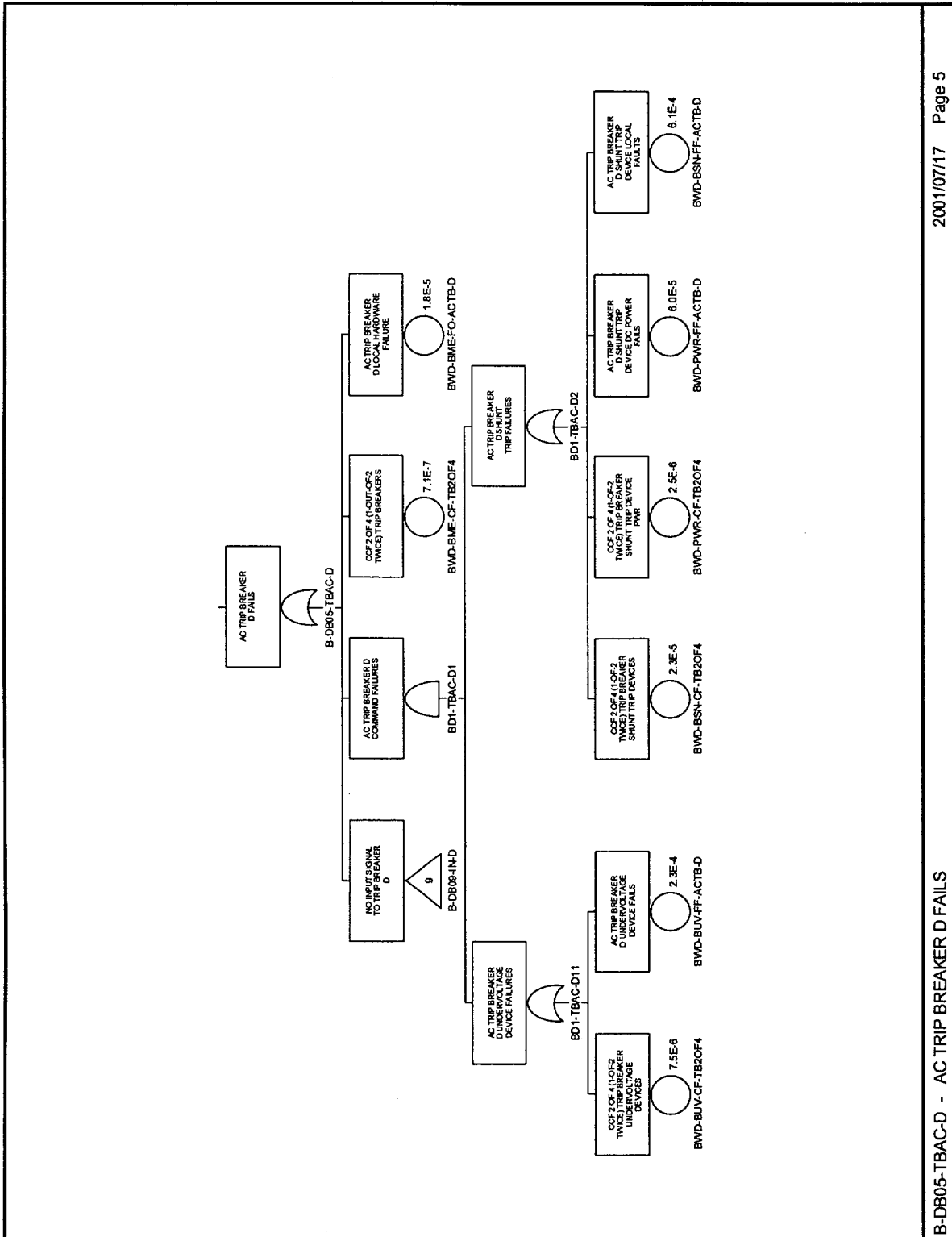
DAVIS-BESSE MODEL

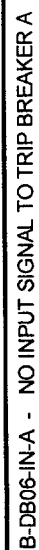


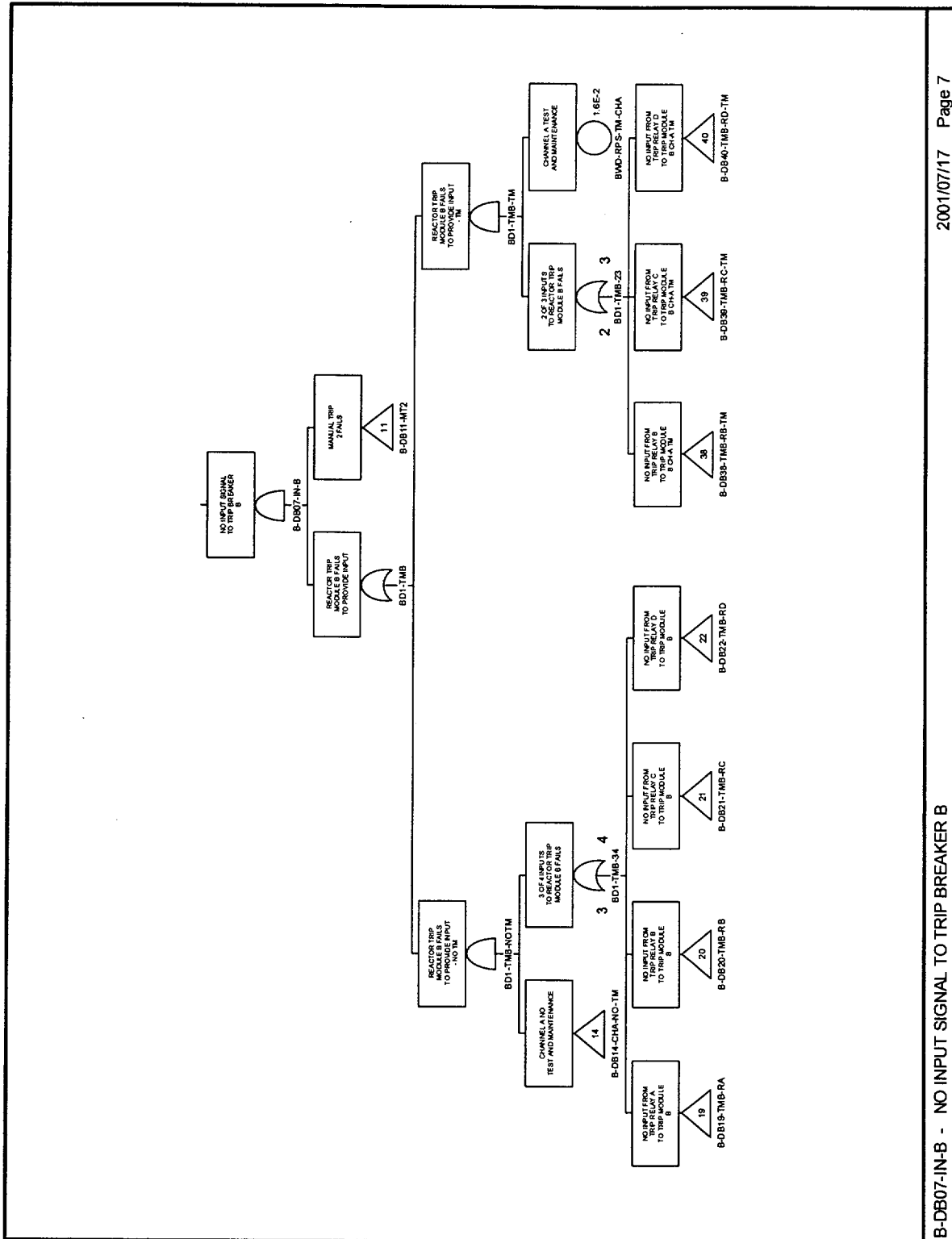


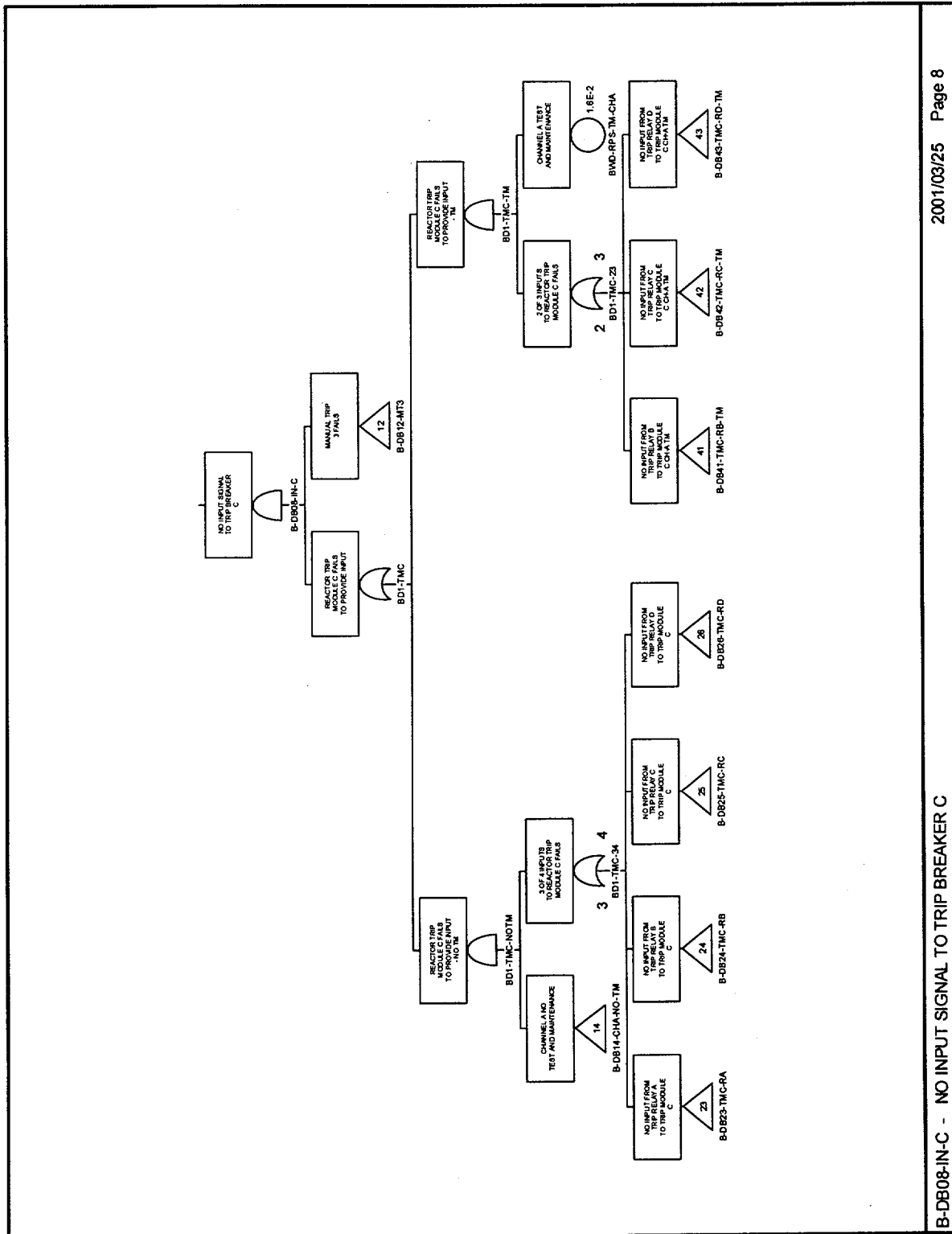


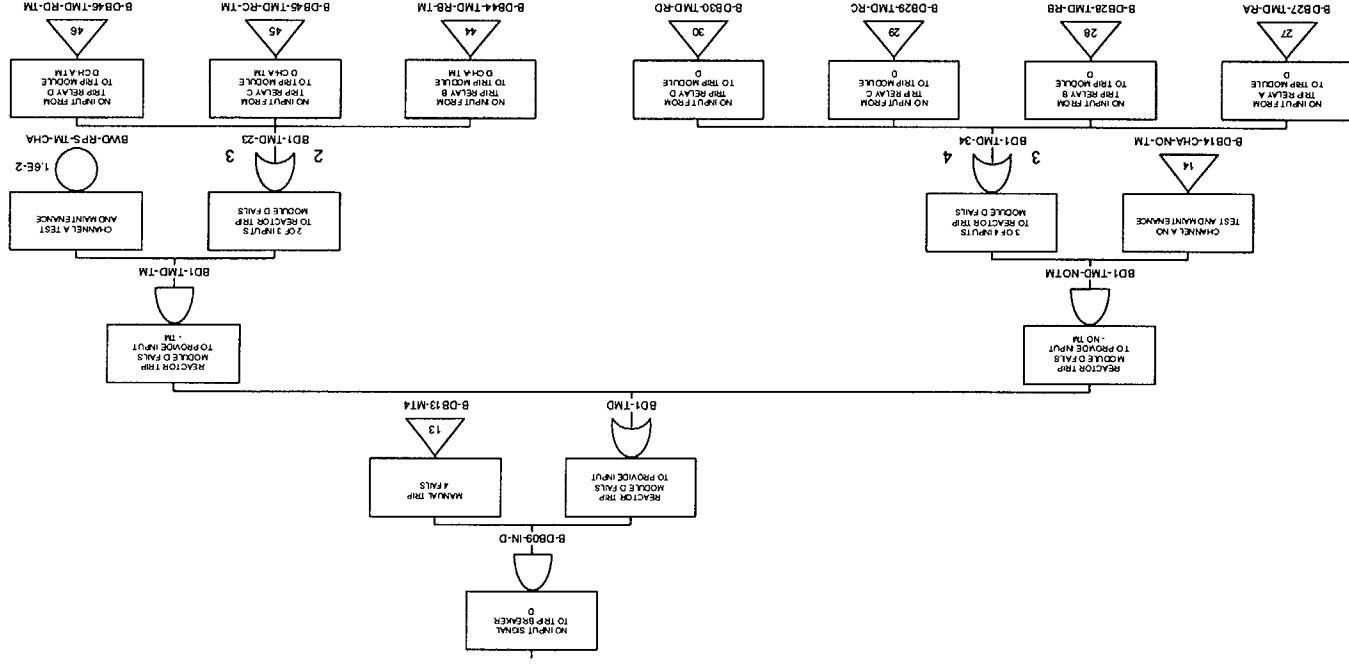


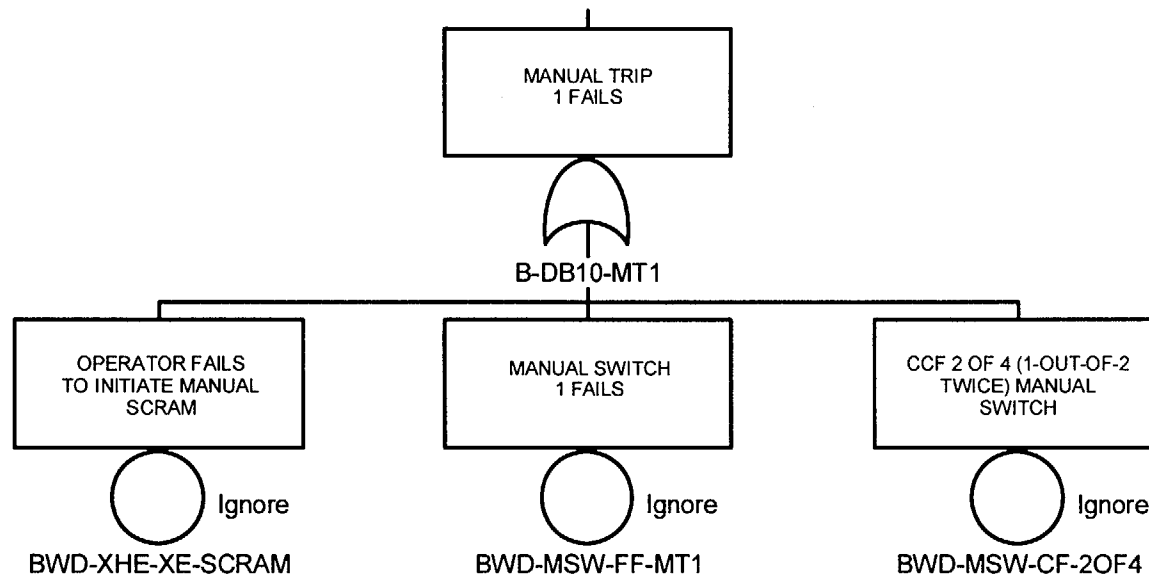




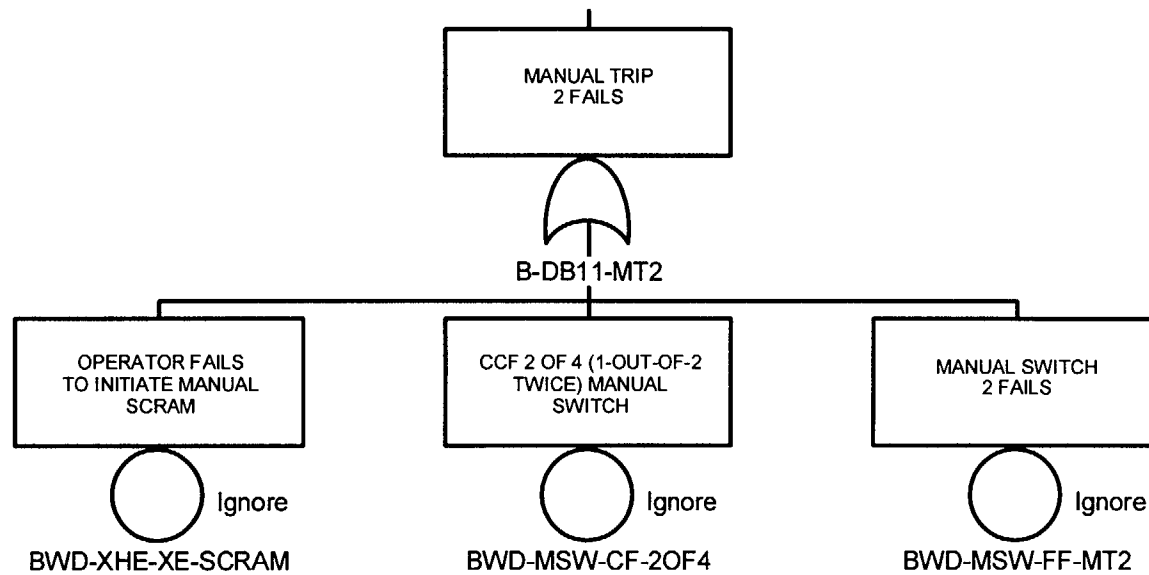


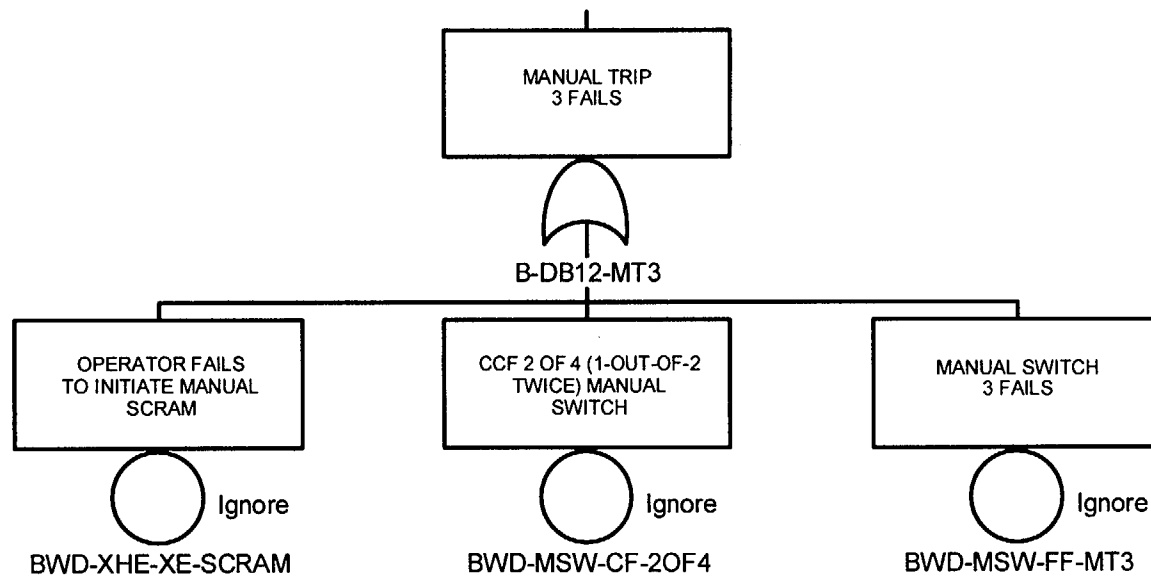




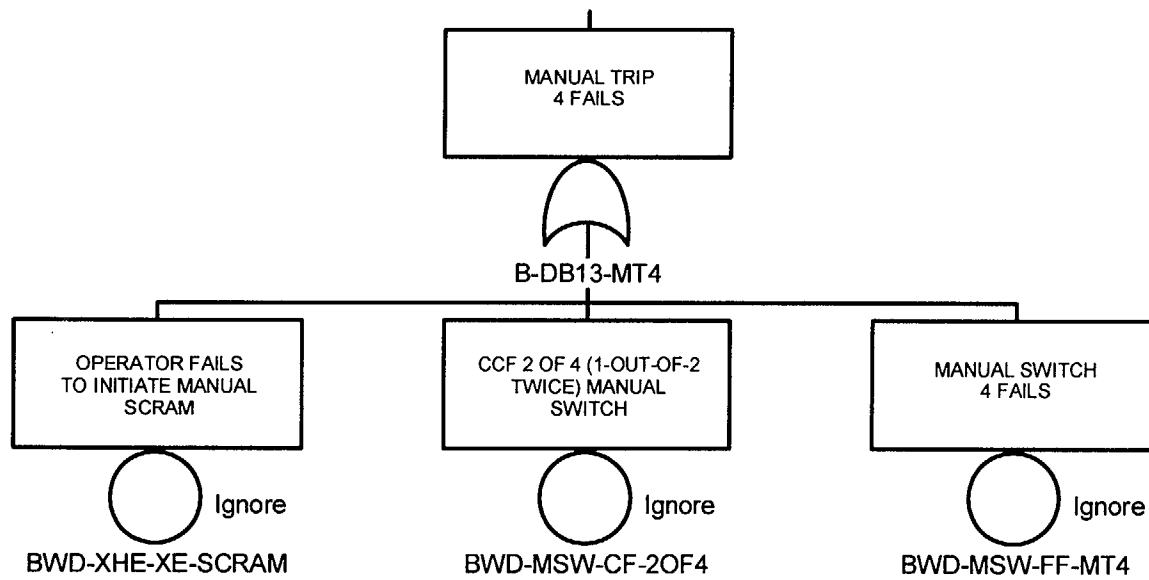


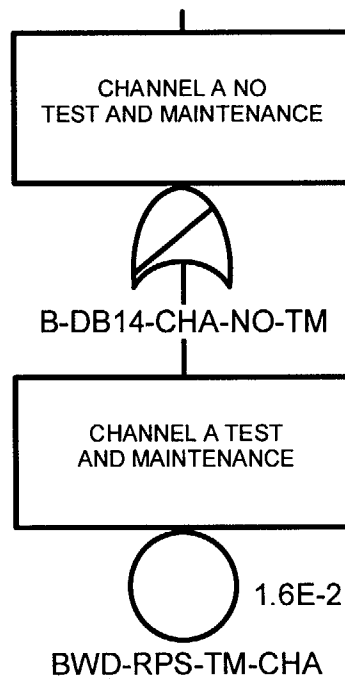
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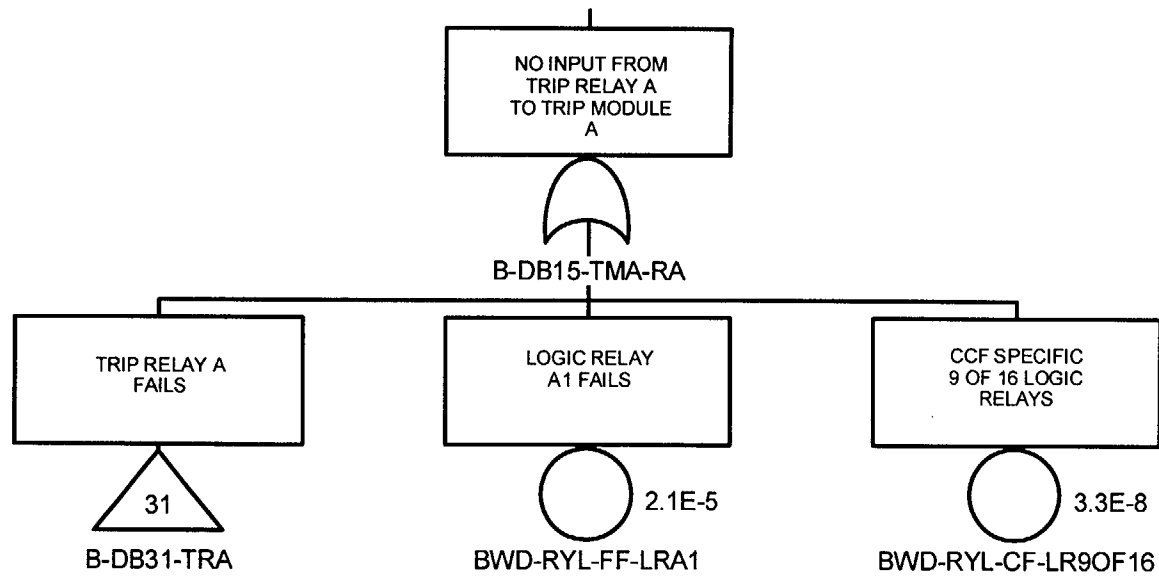


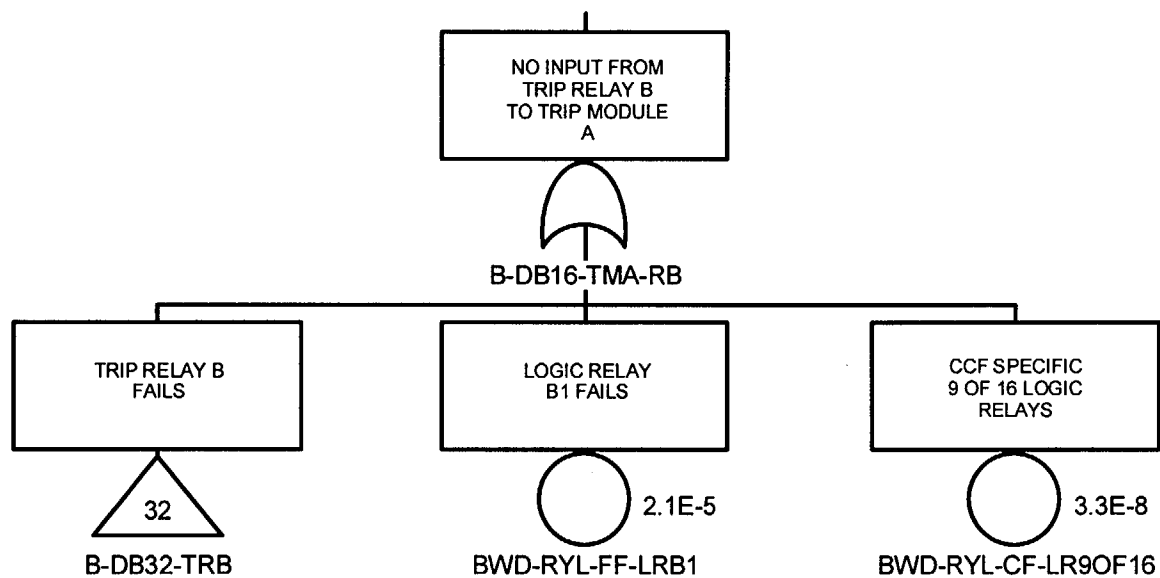
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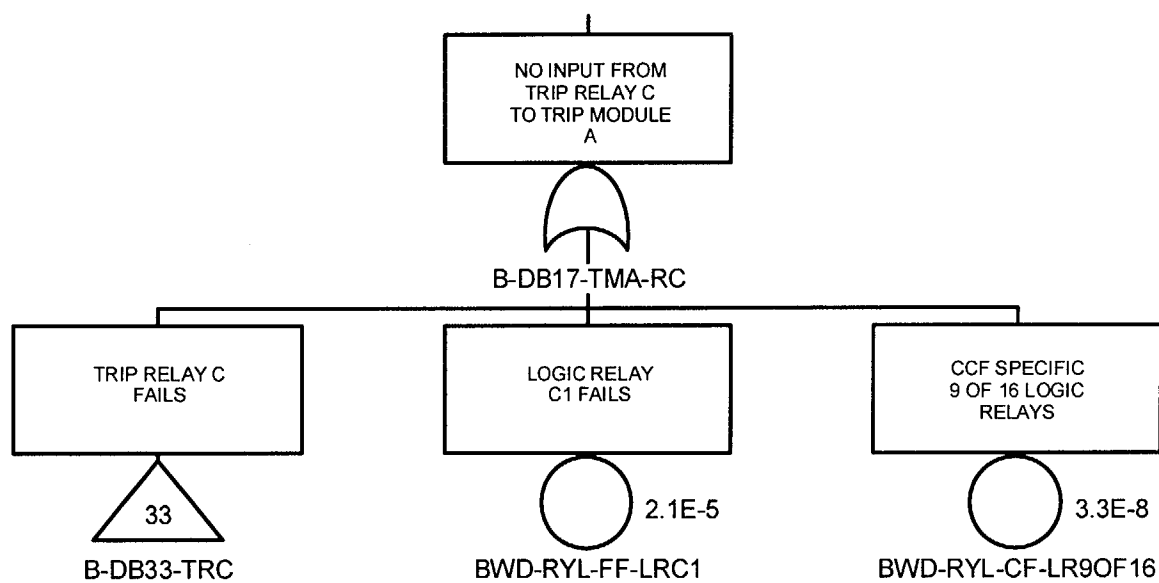


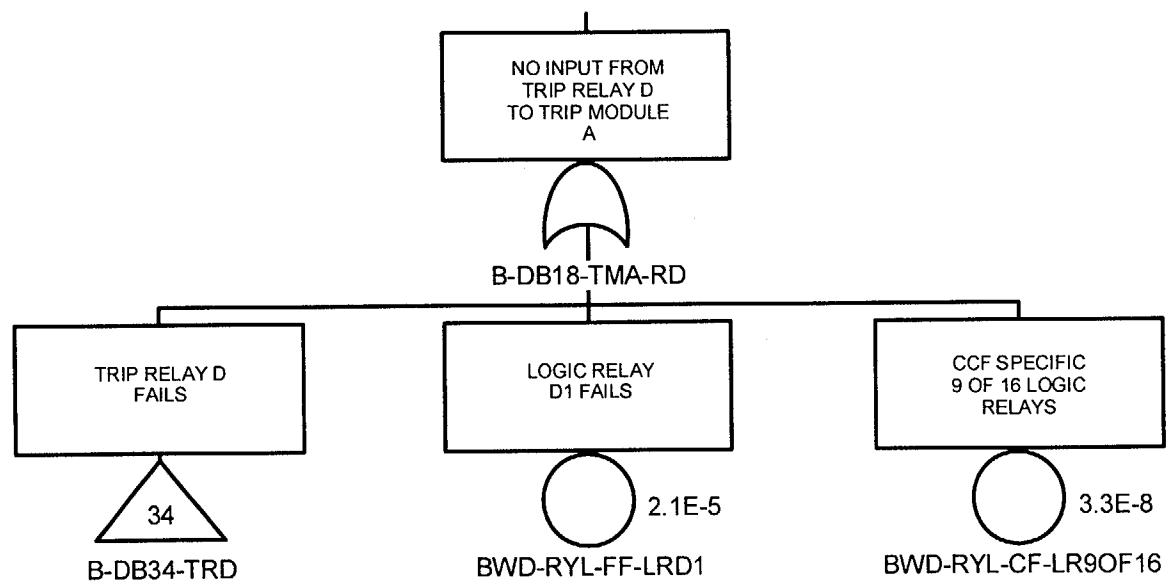


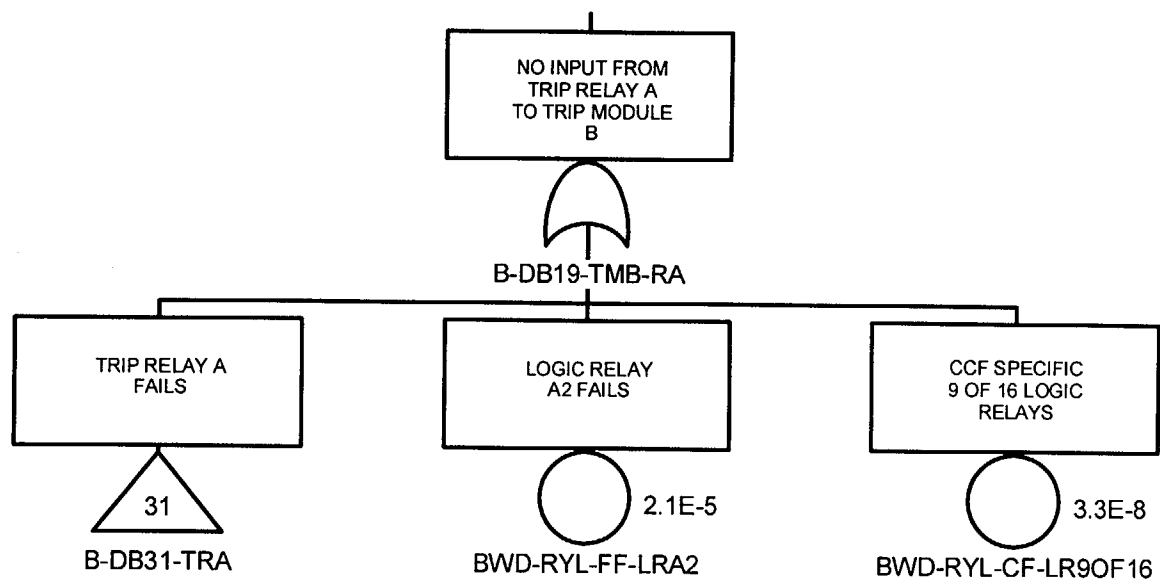
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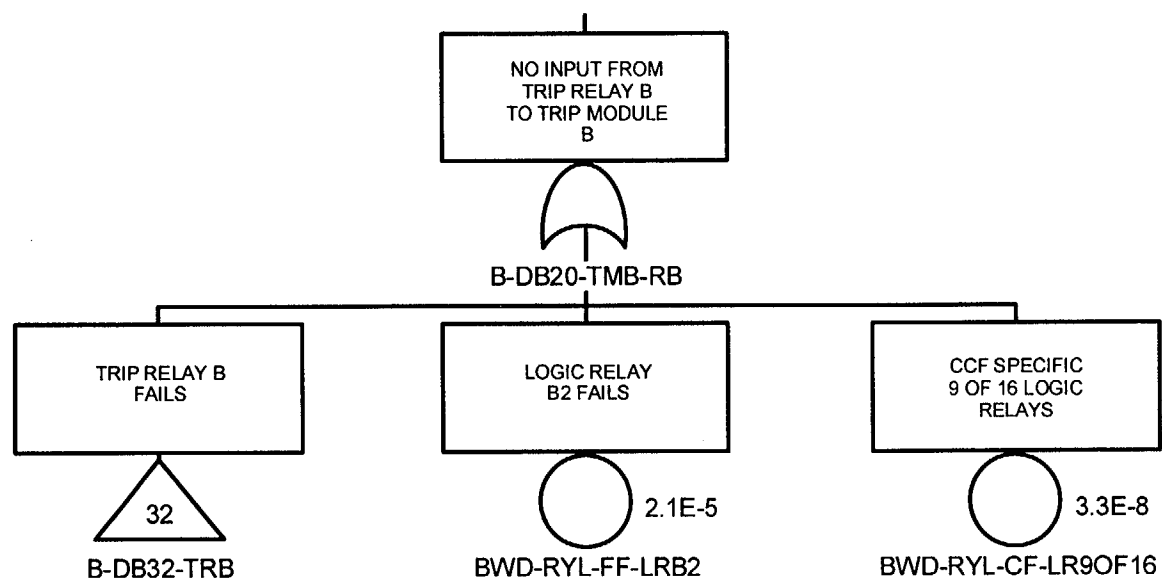




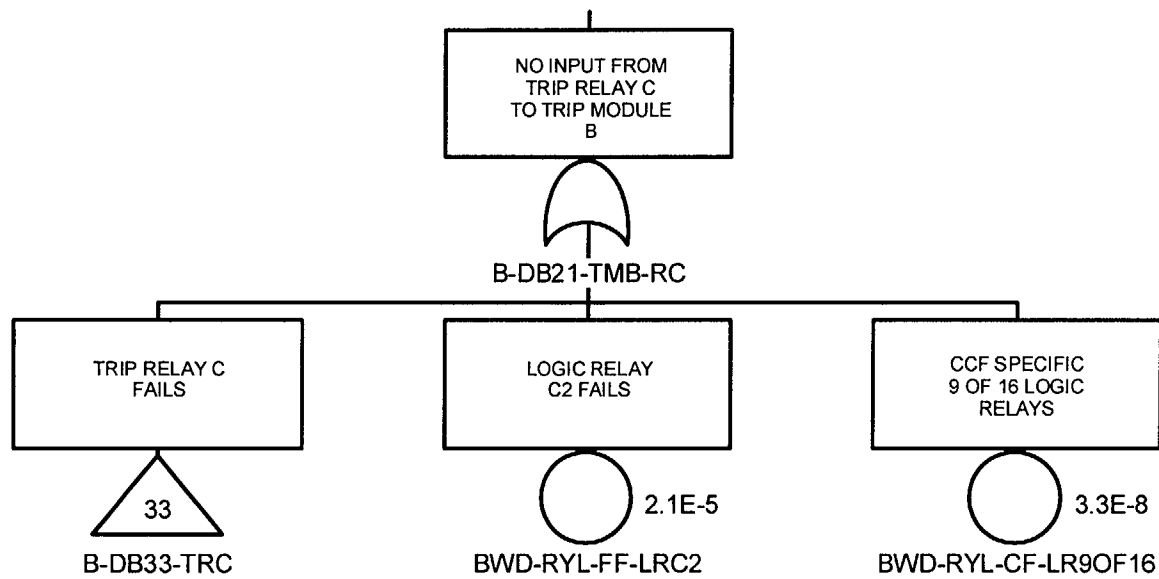


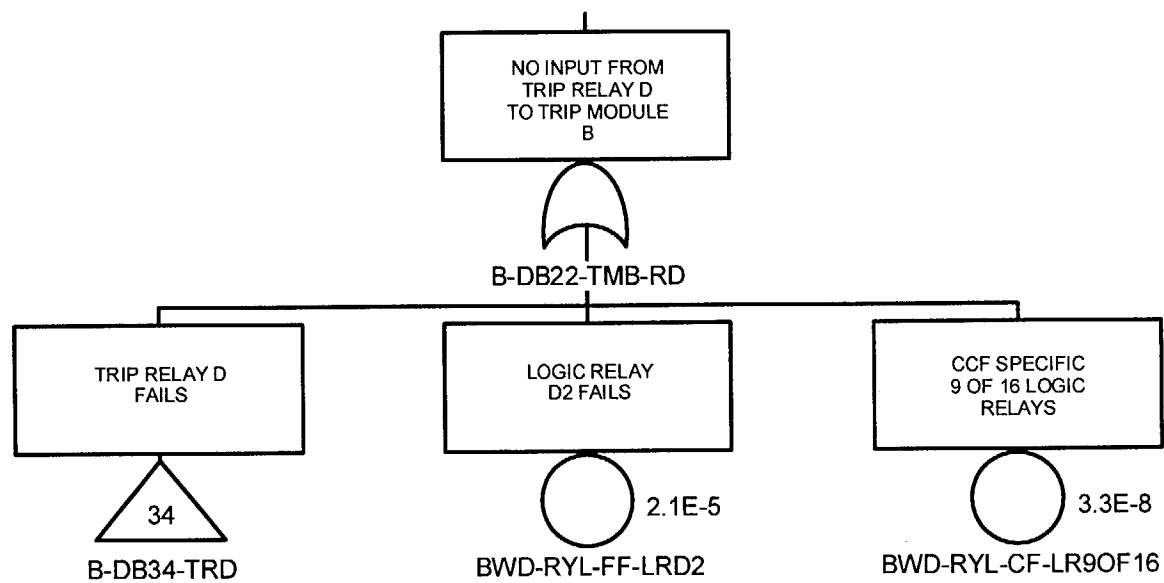




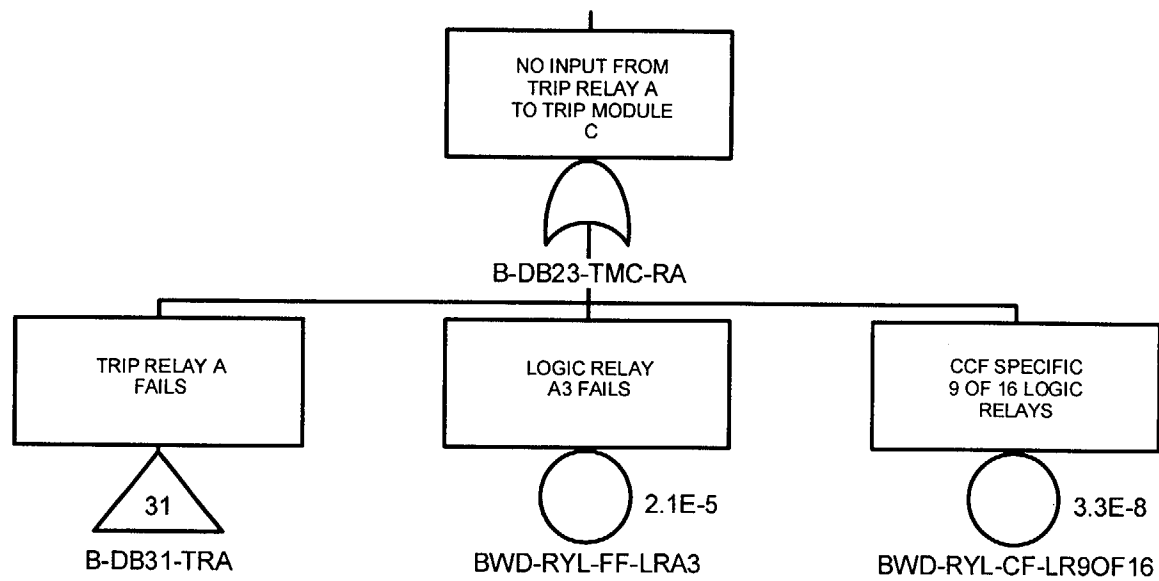


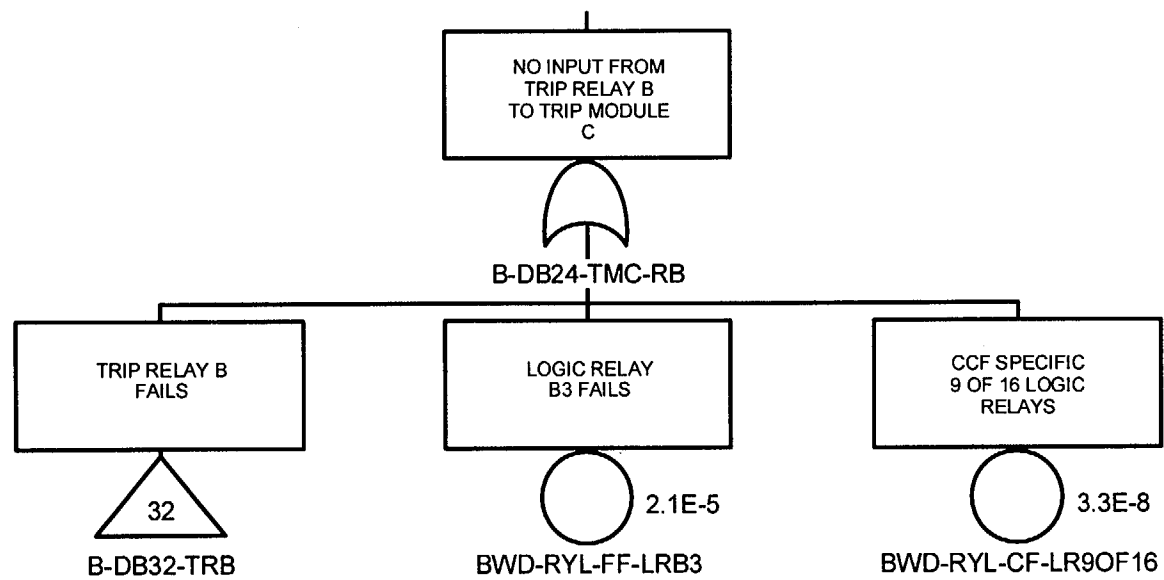
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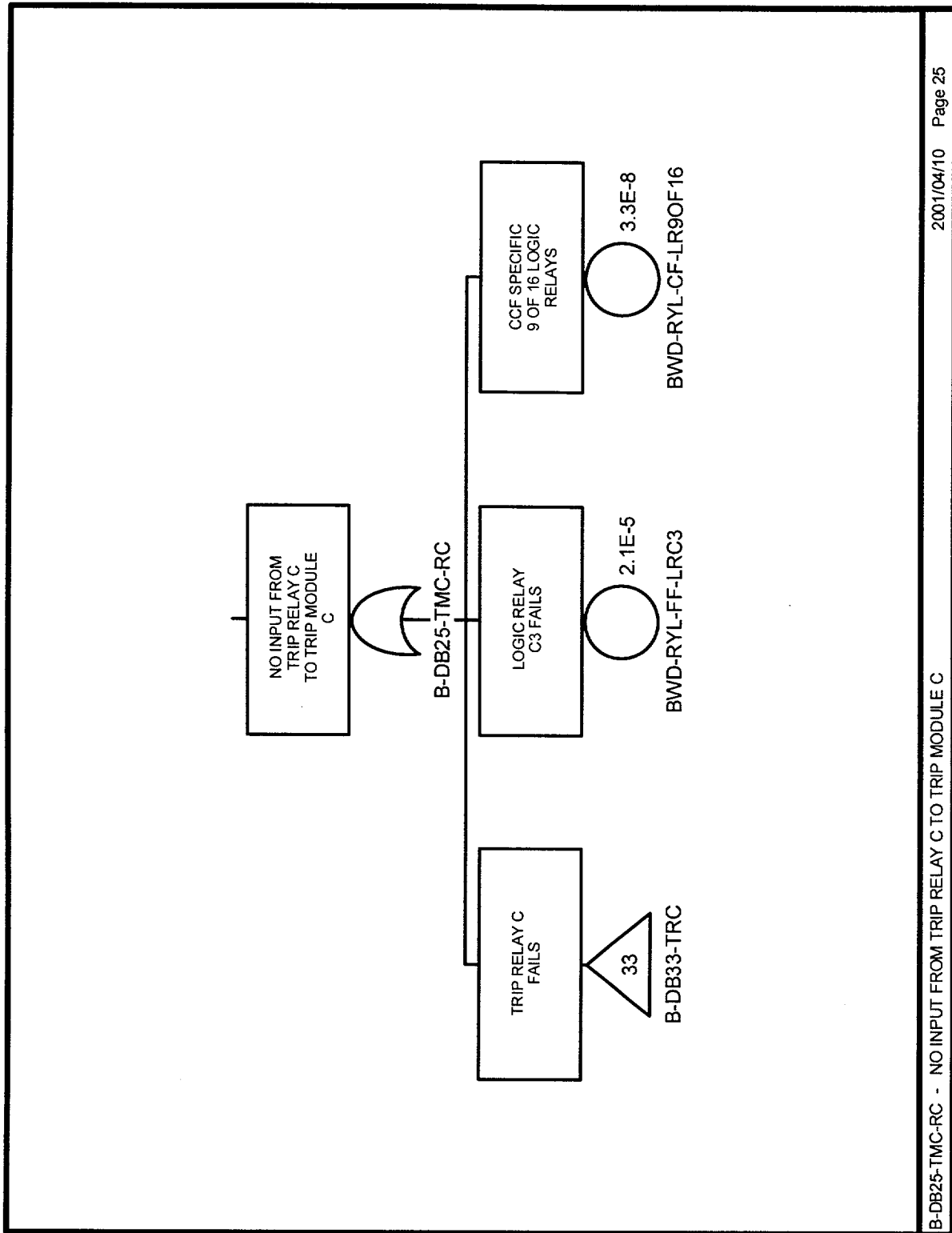


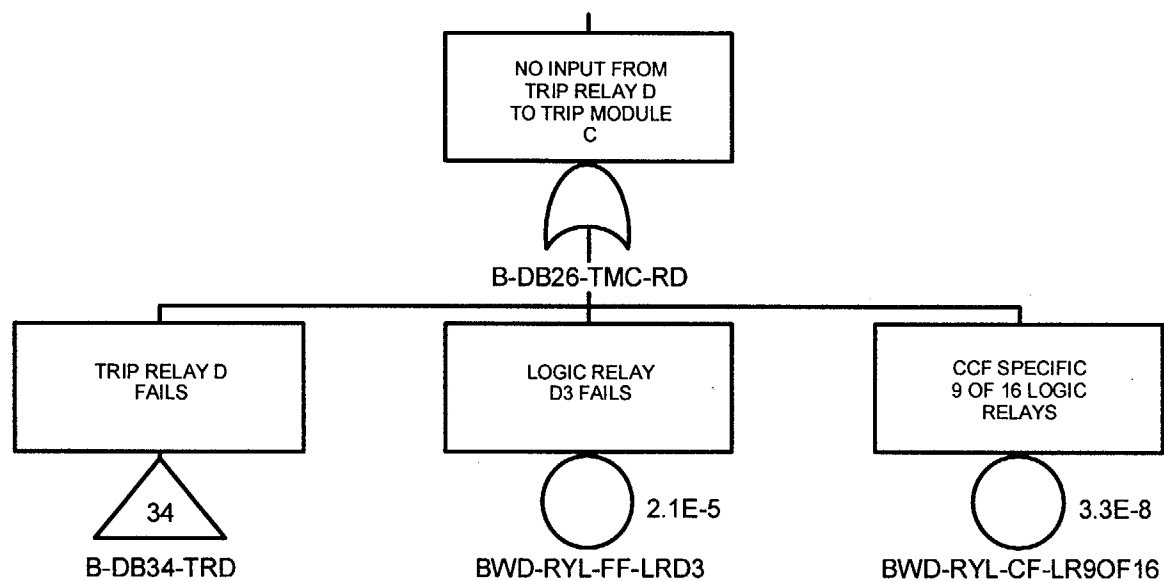


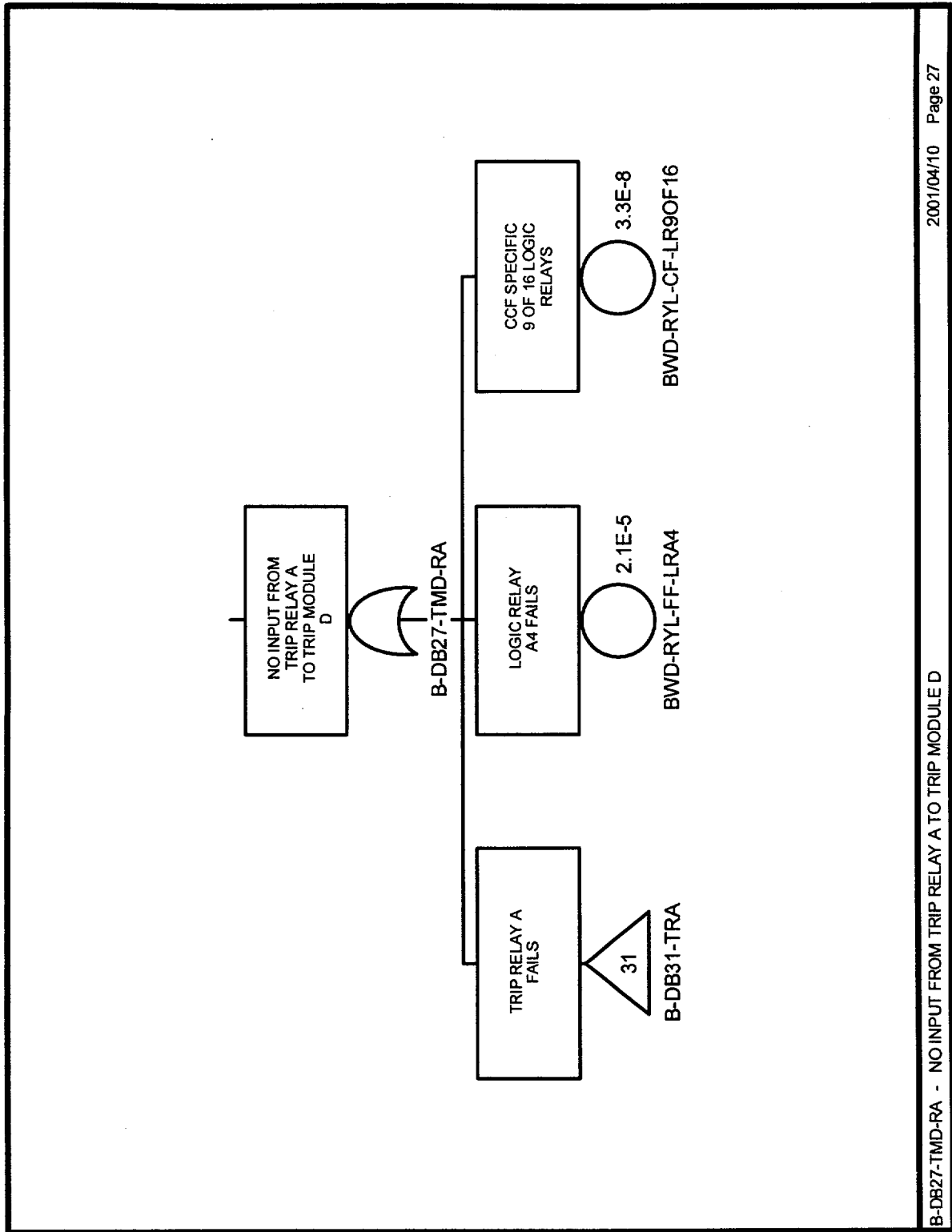
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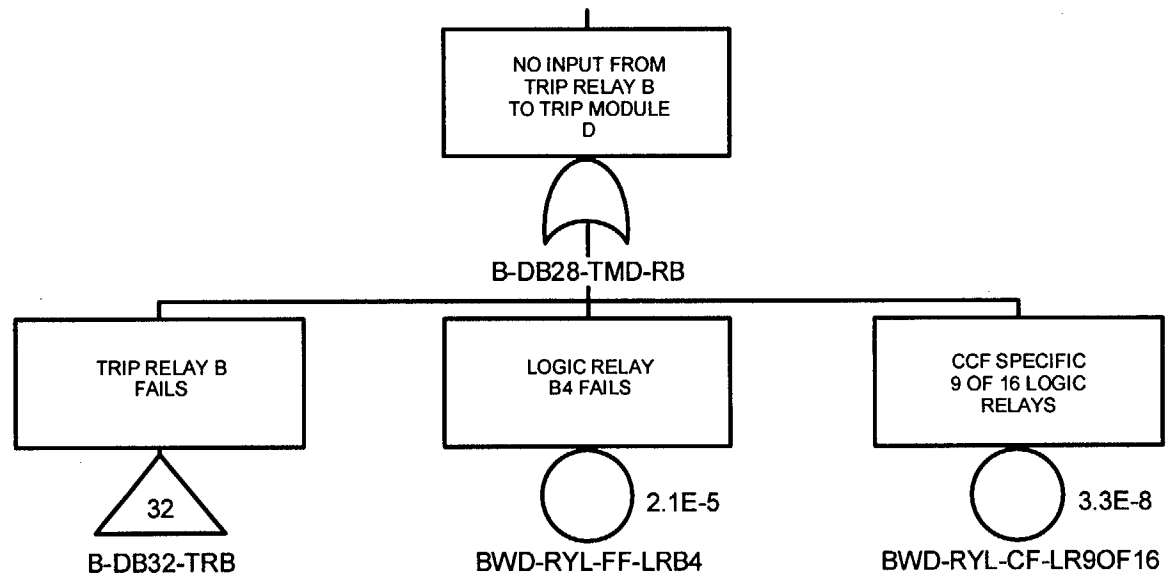




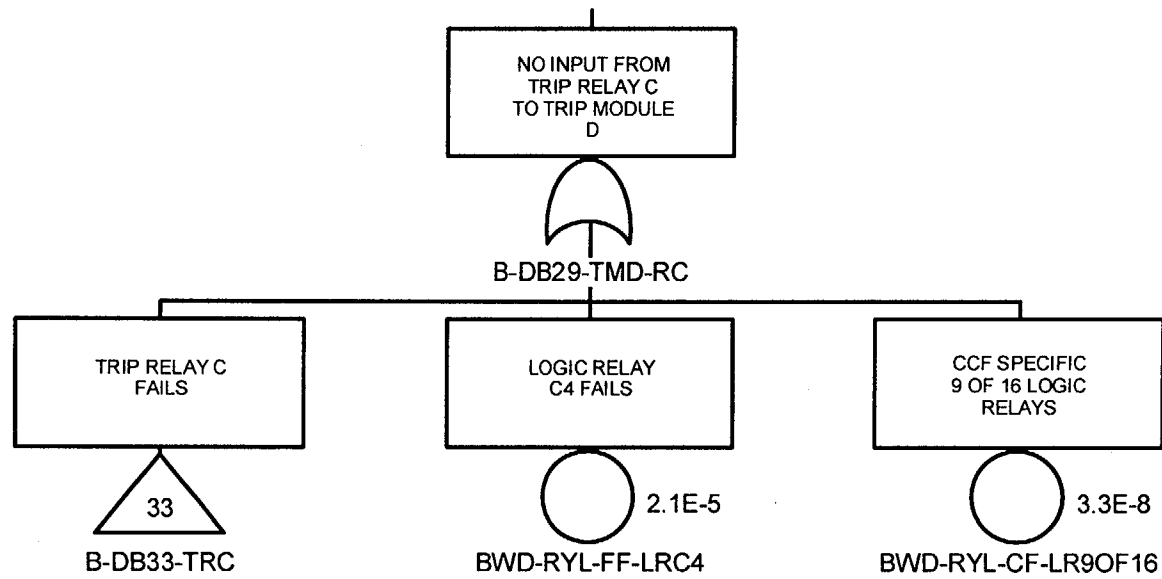


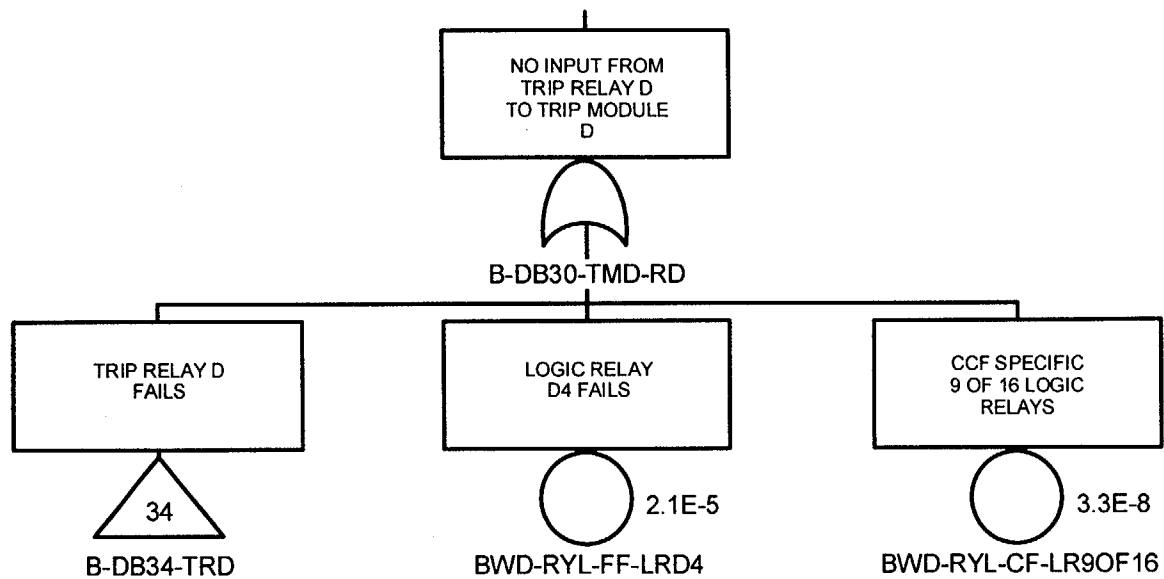


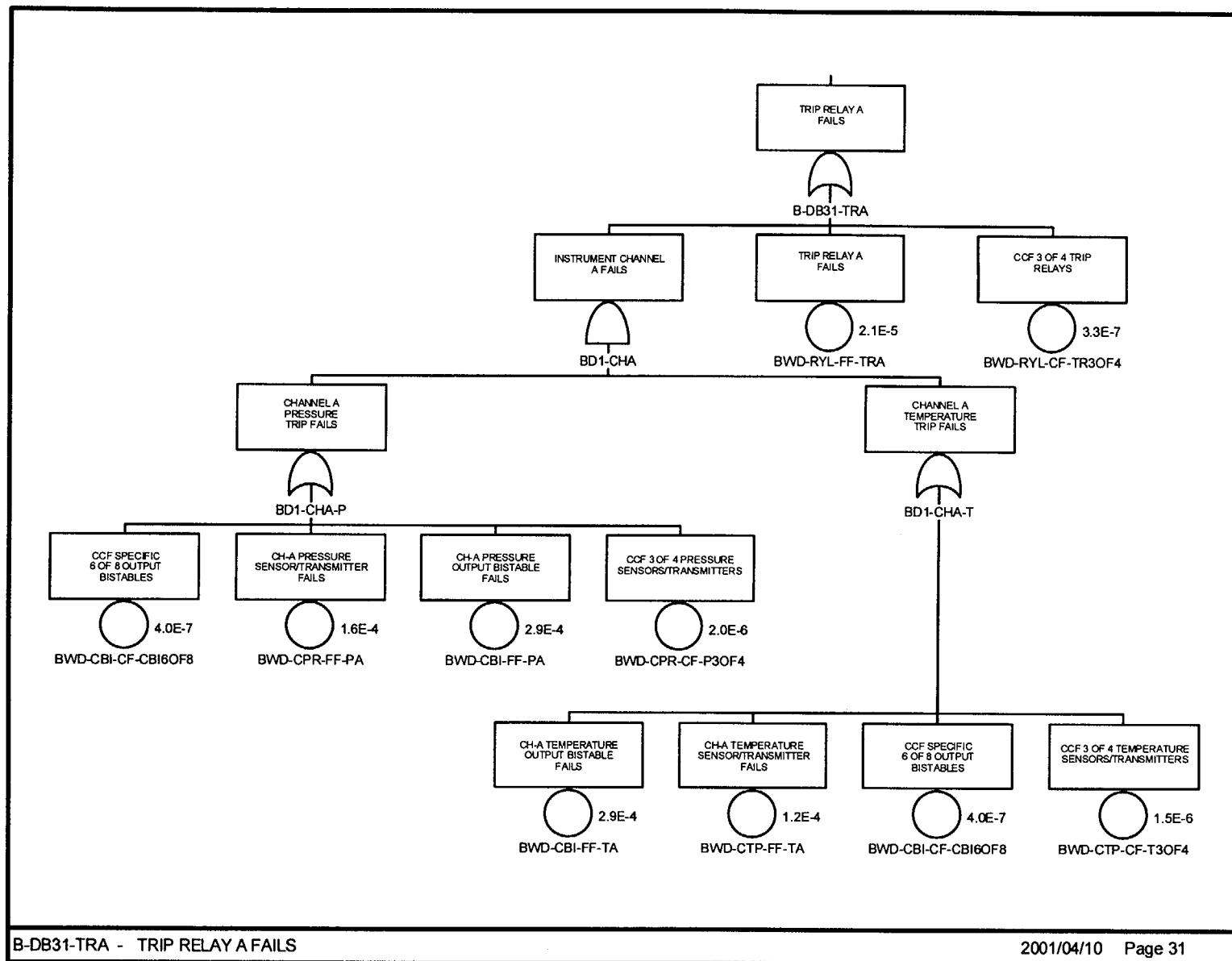


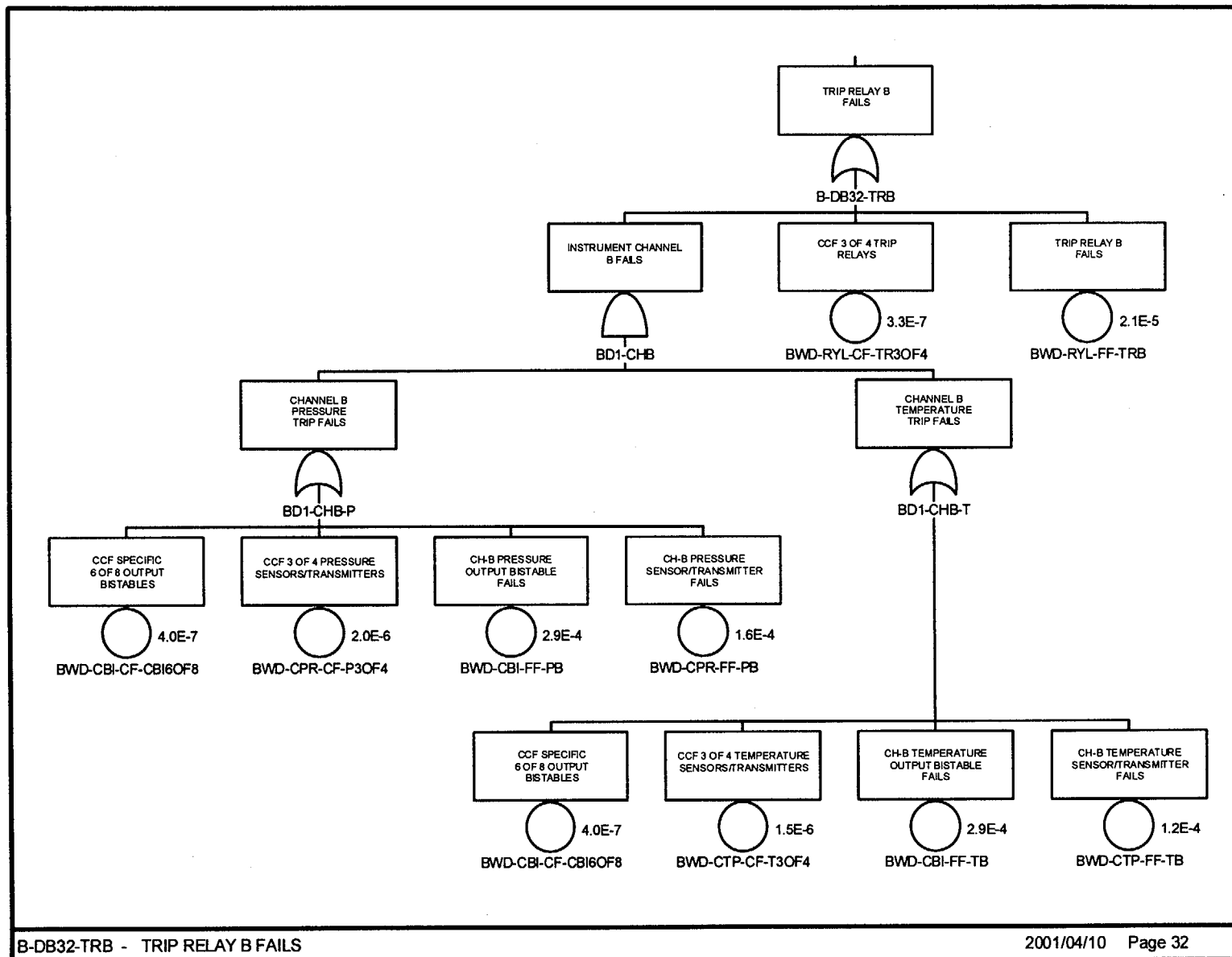


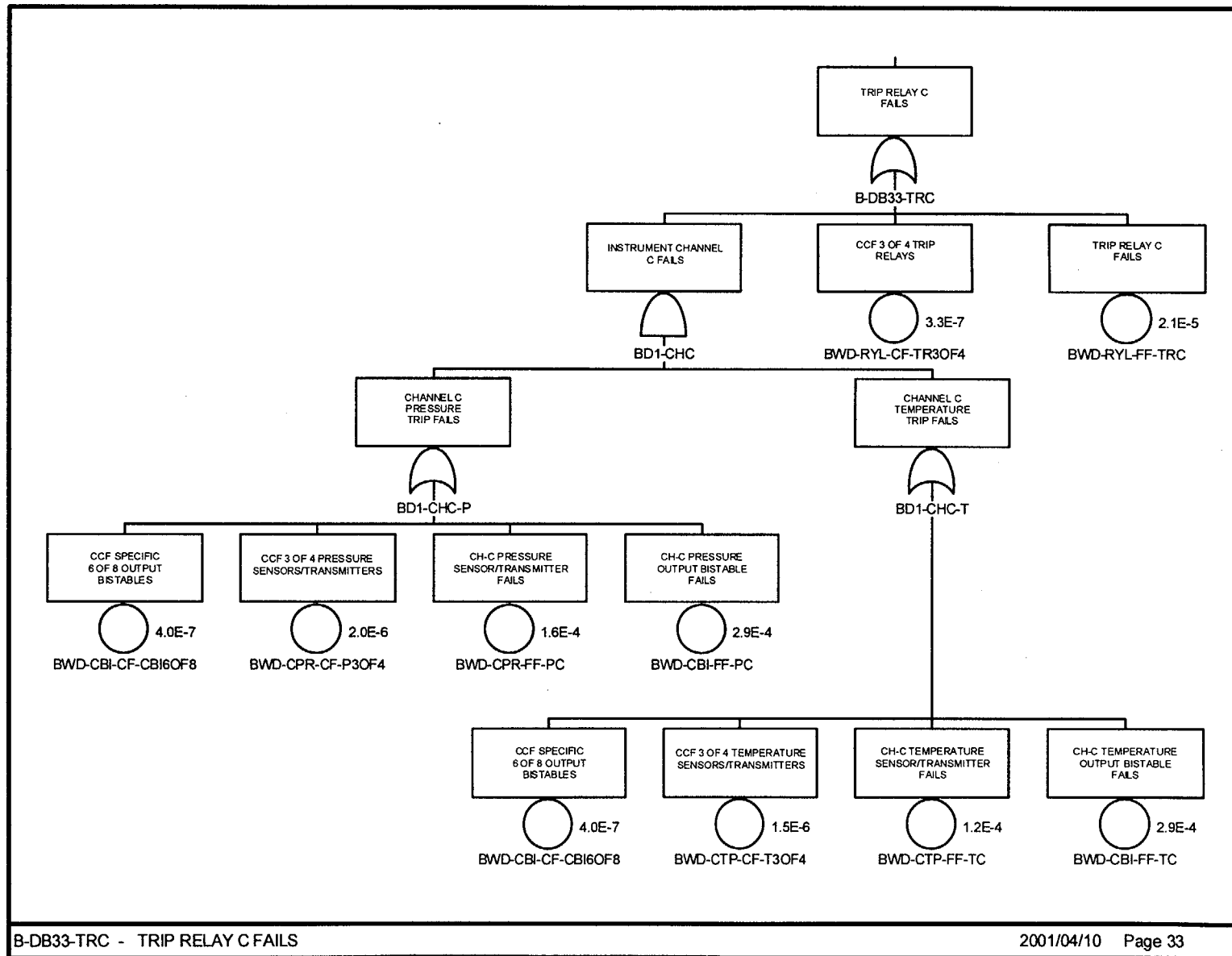
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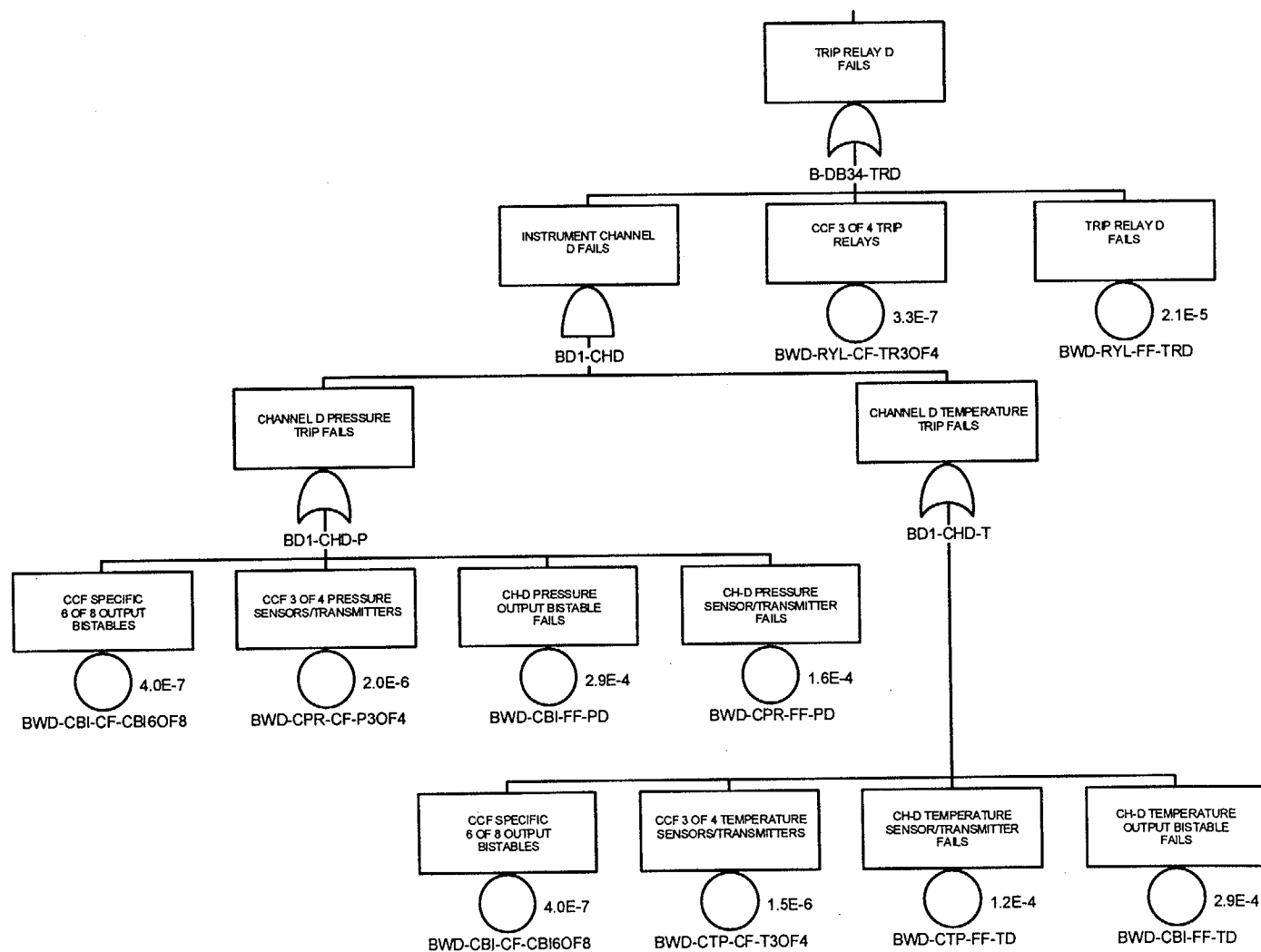




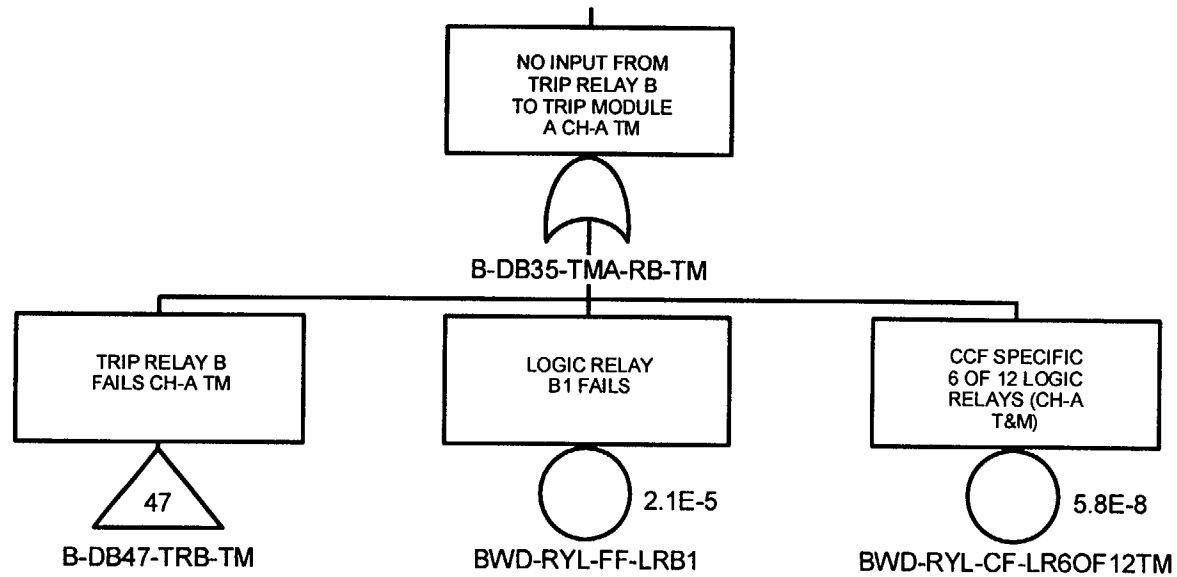


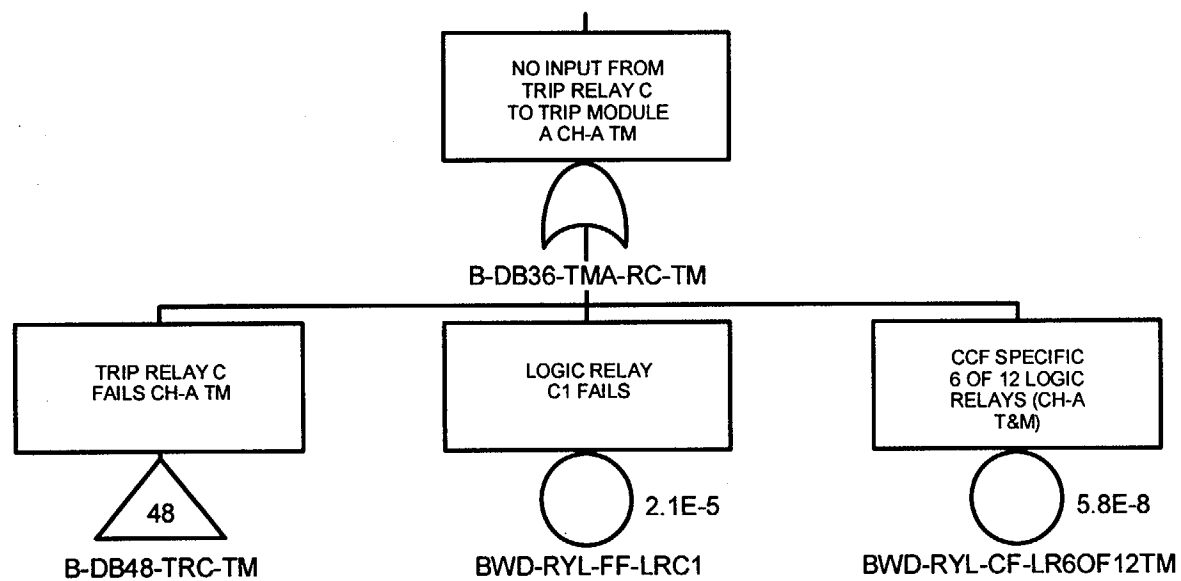




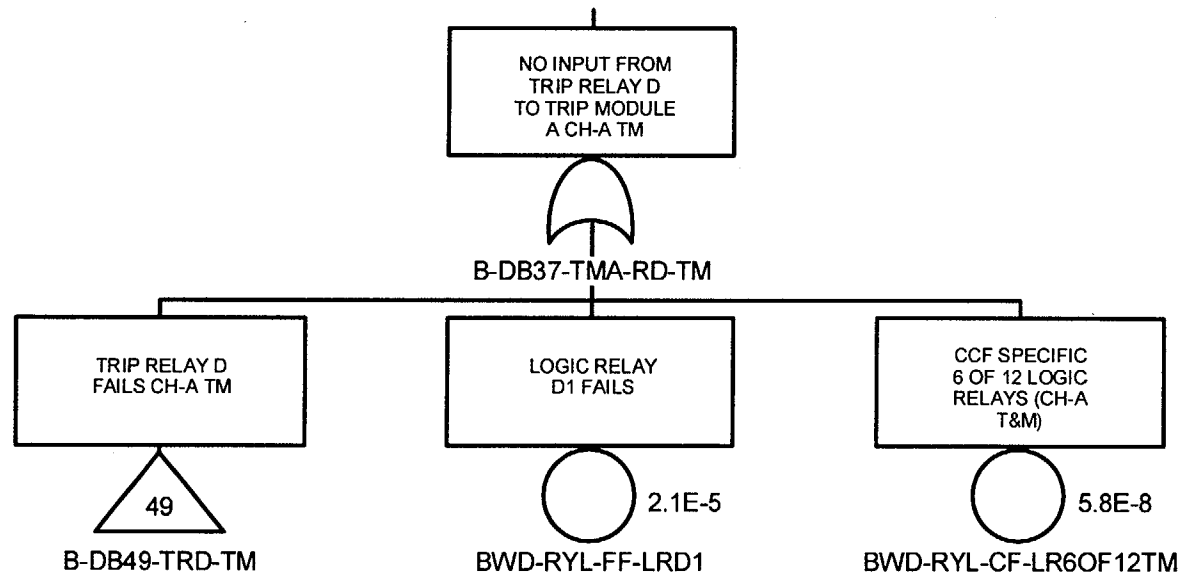


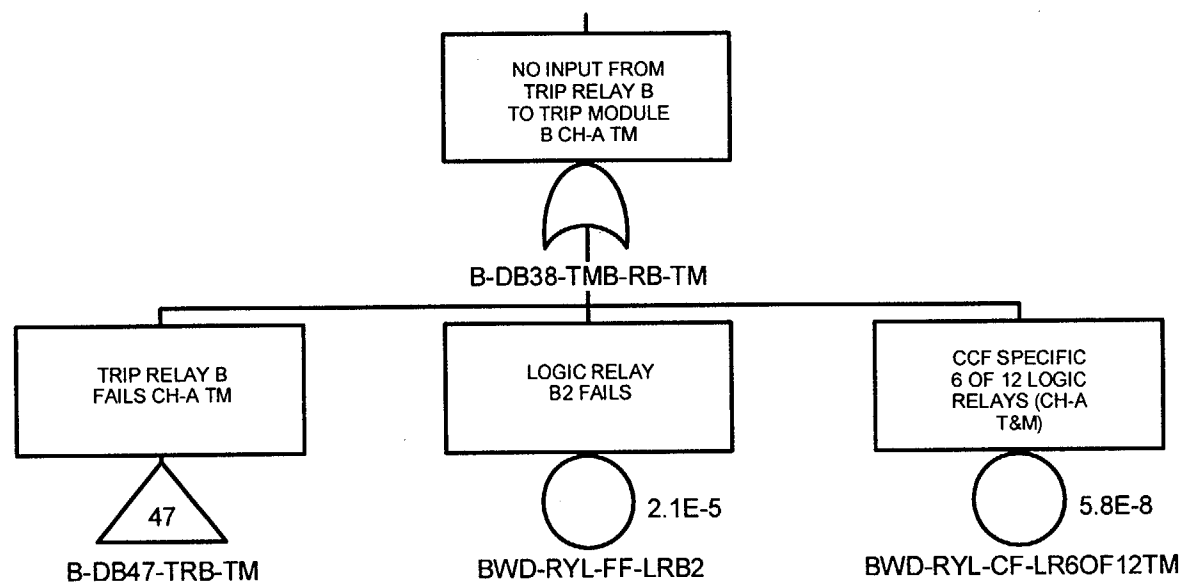
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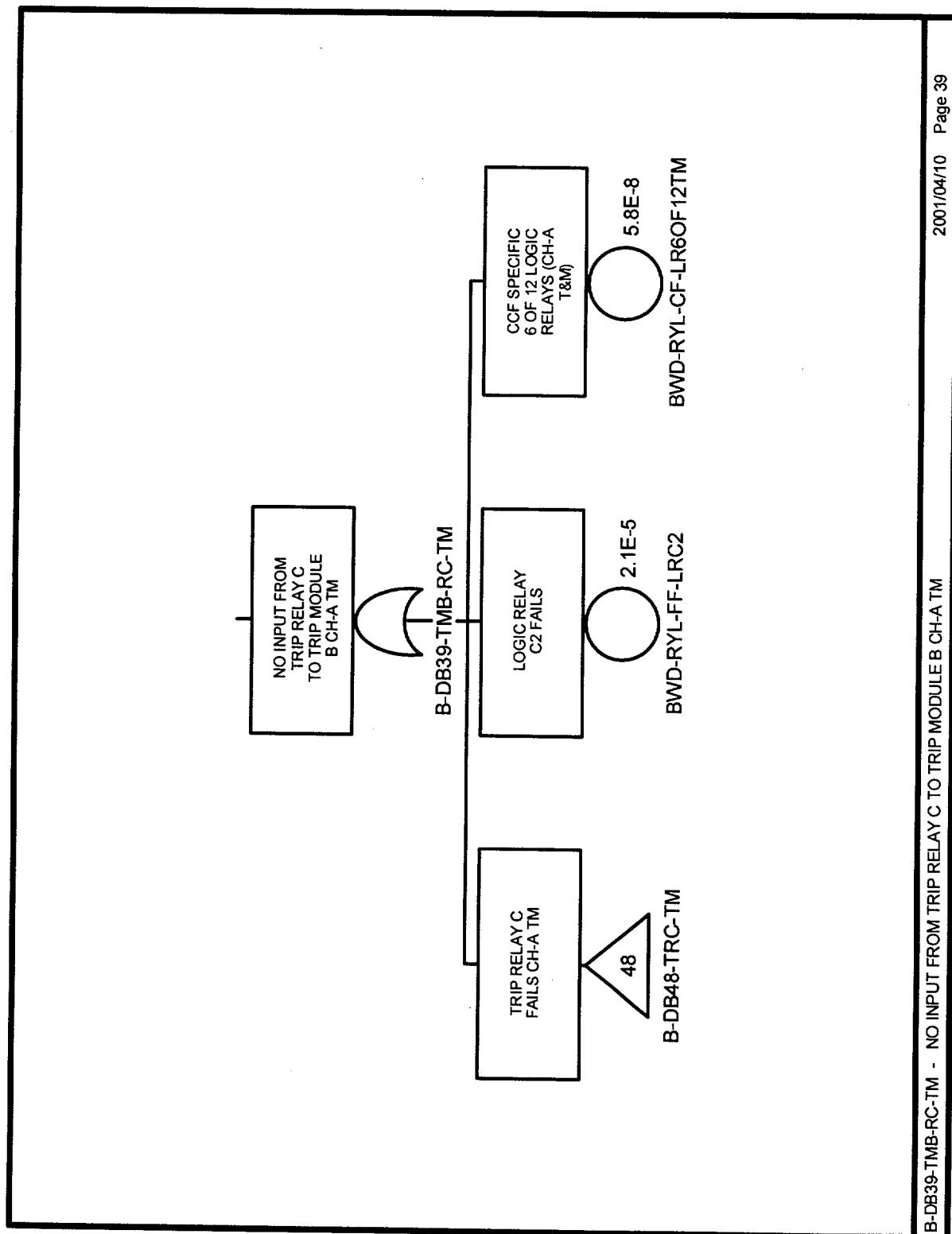


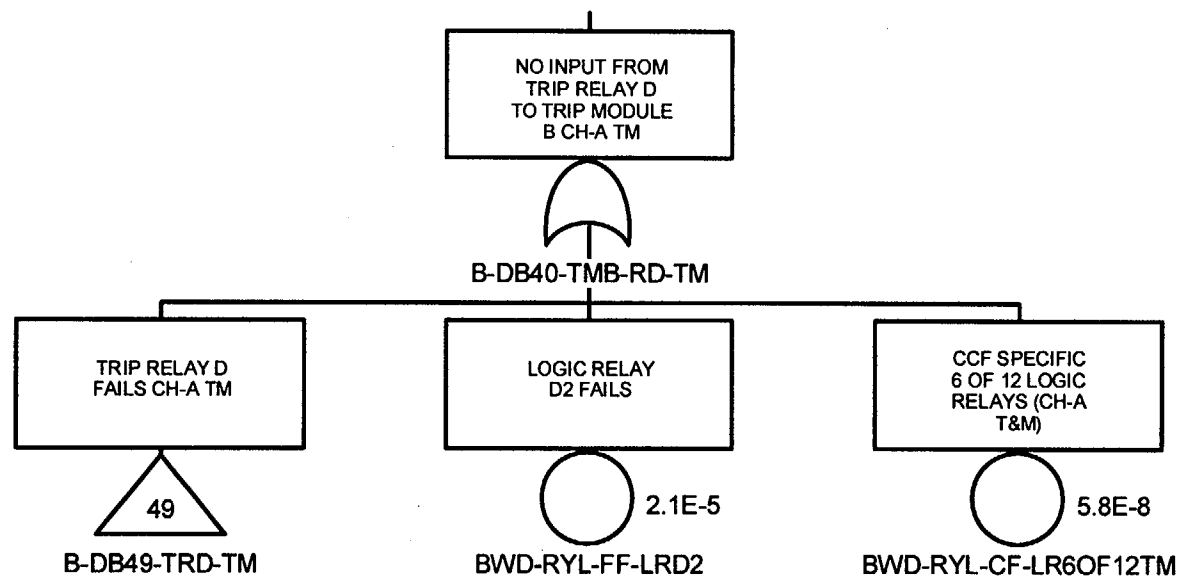


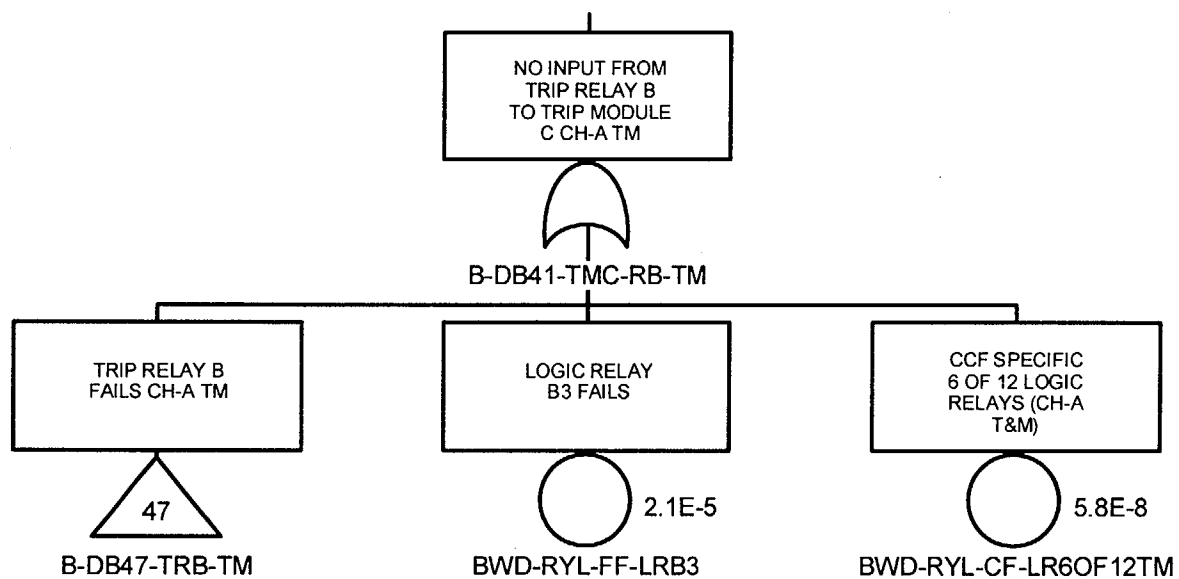
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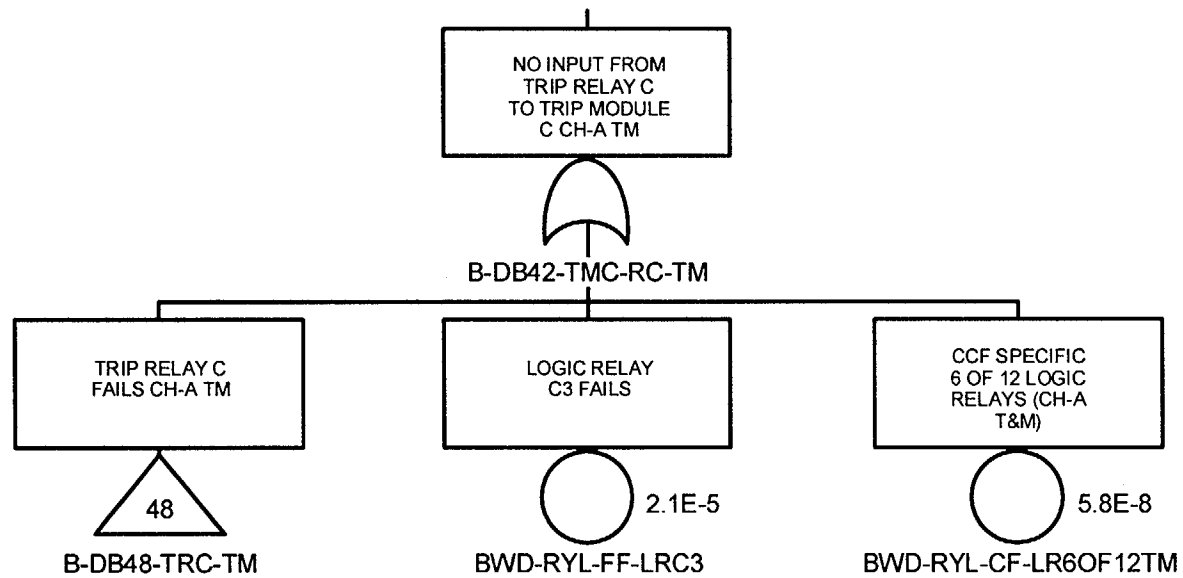


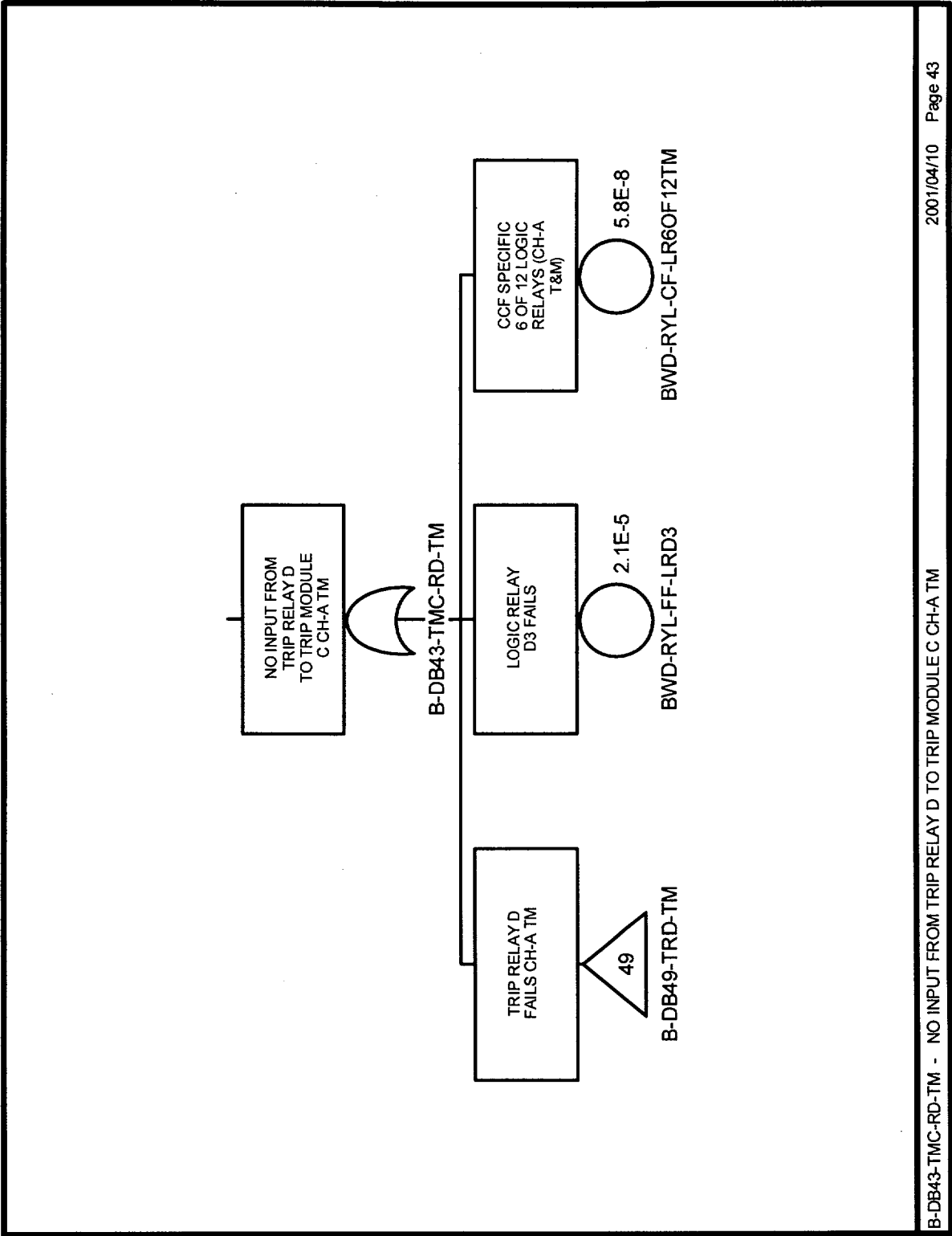


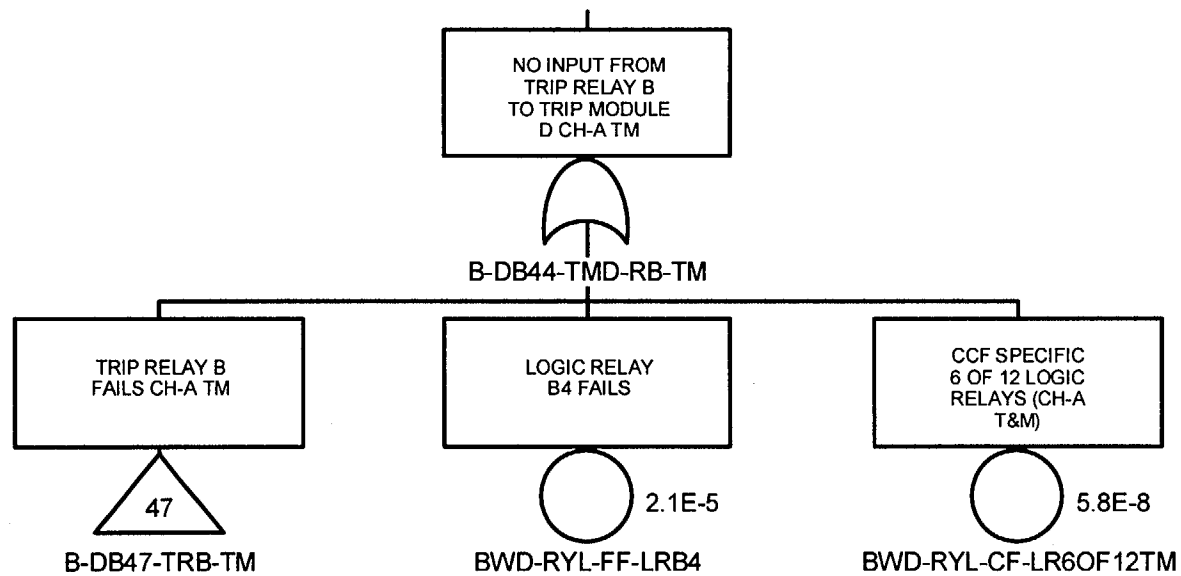


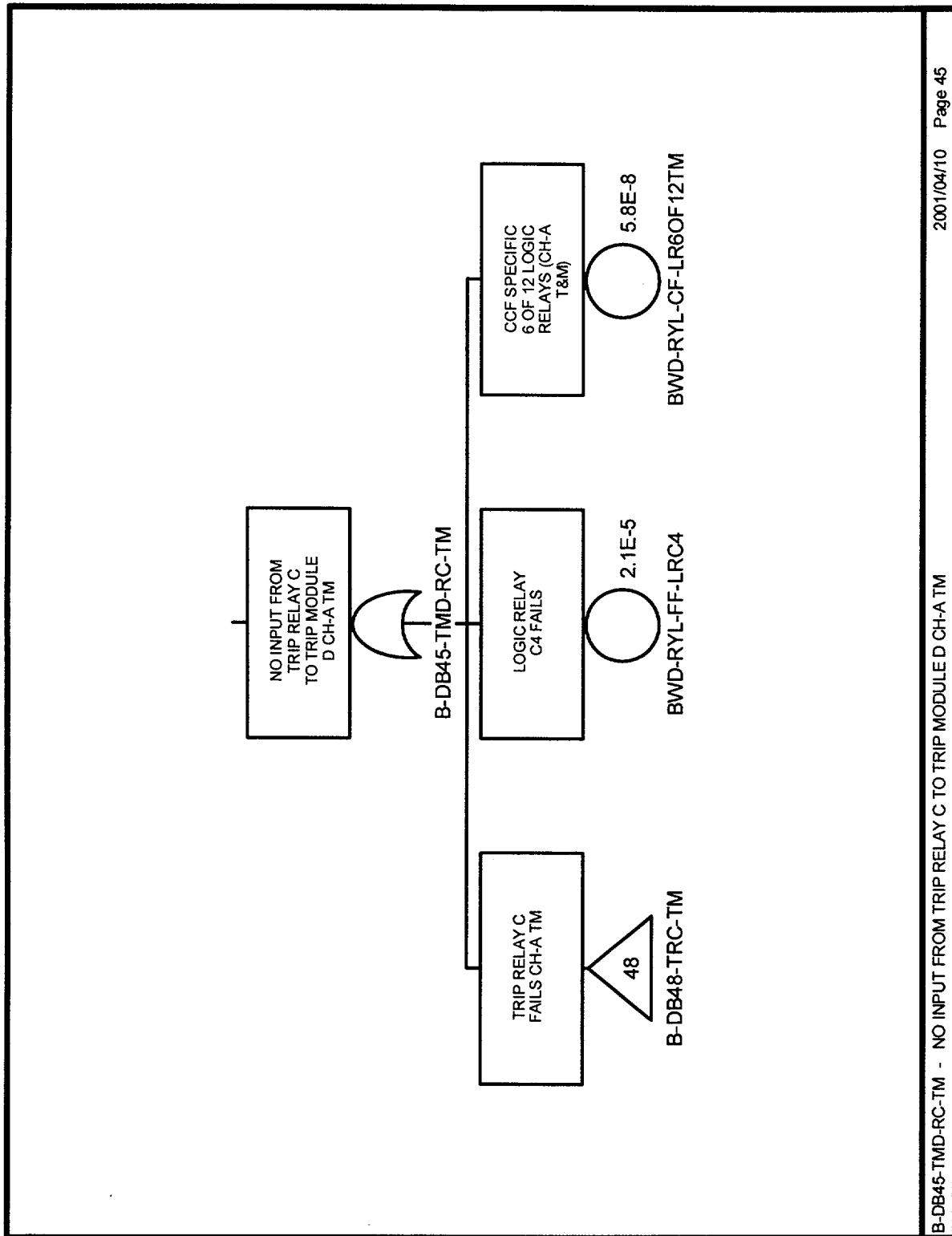


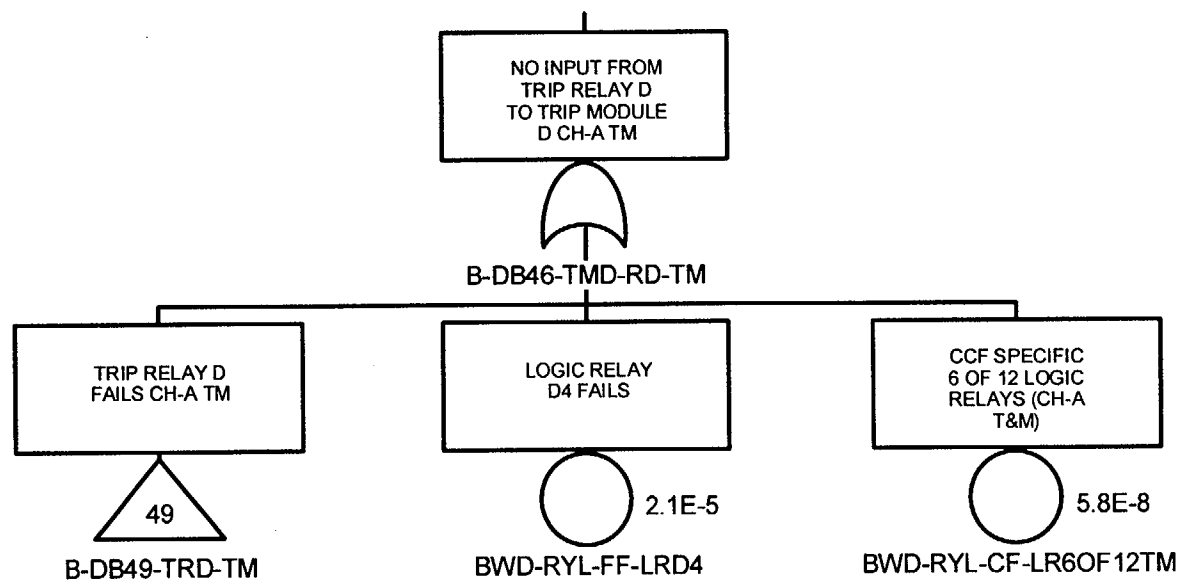


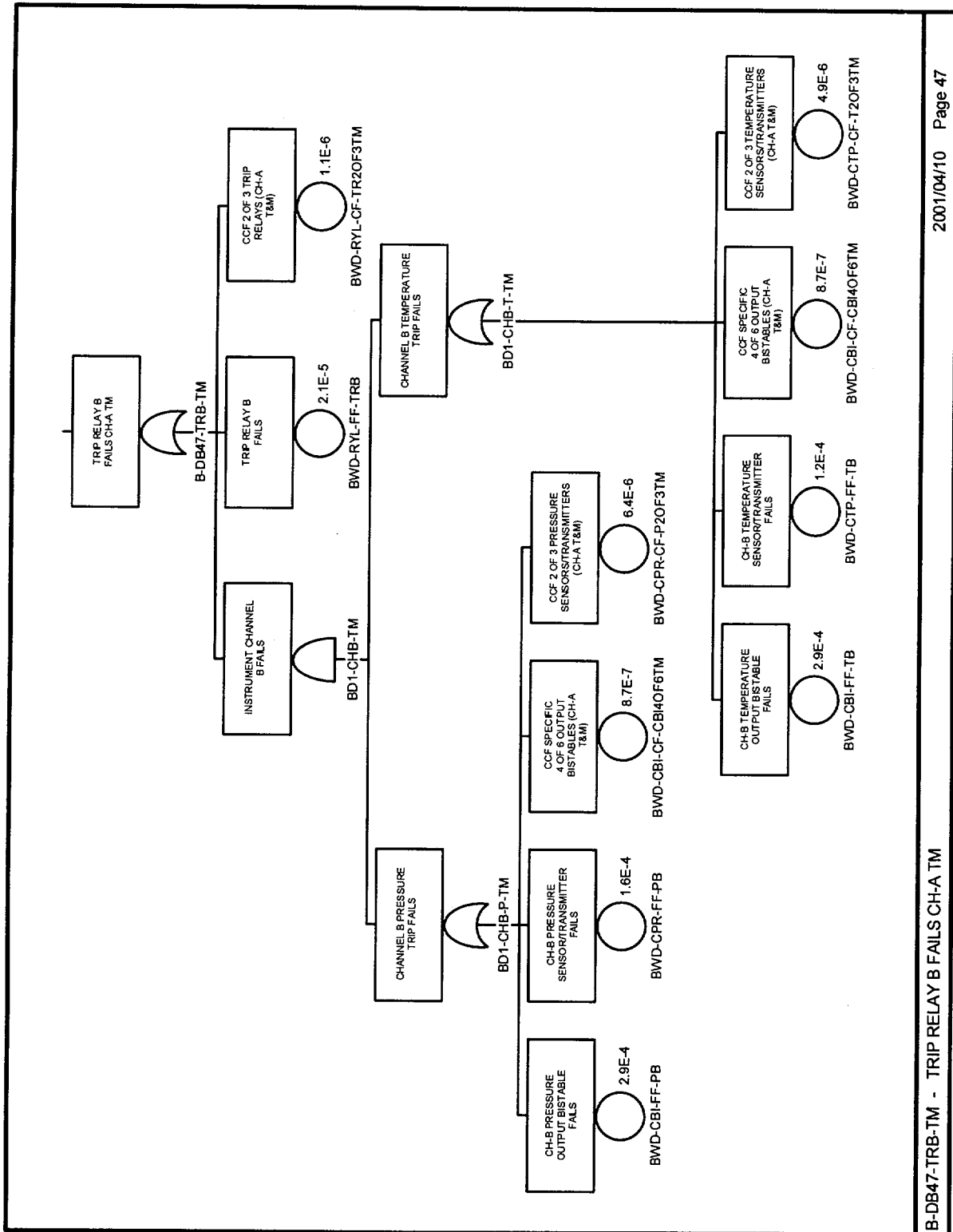


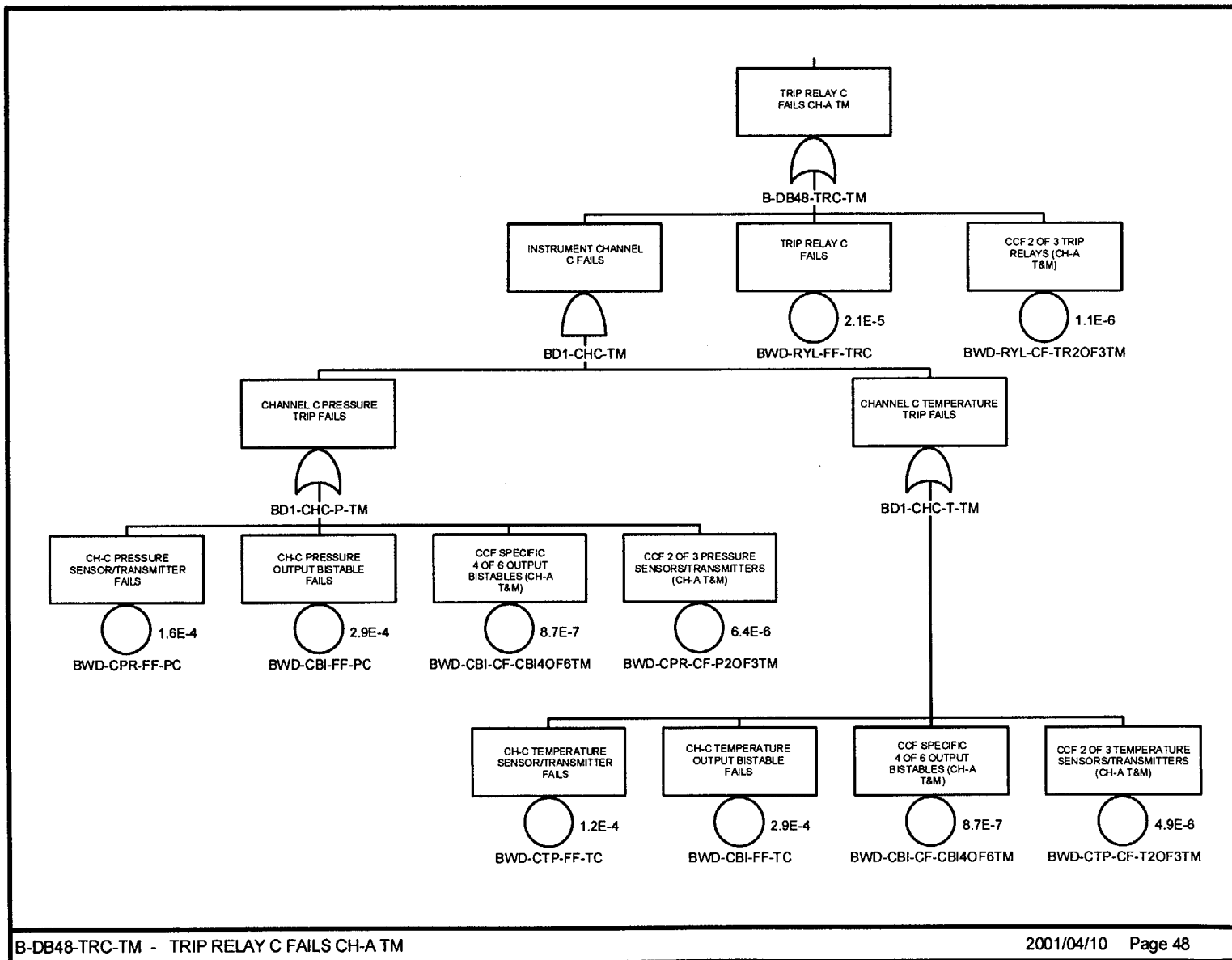


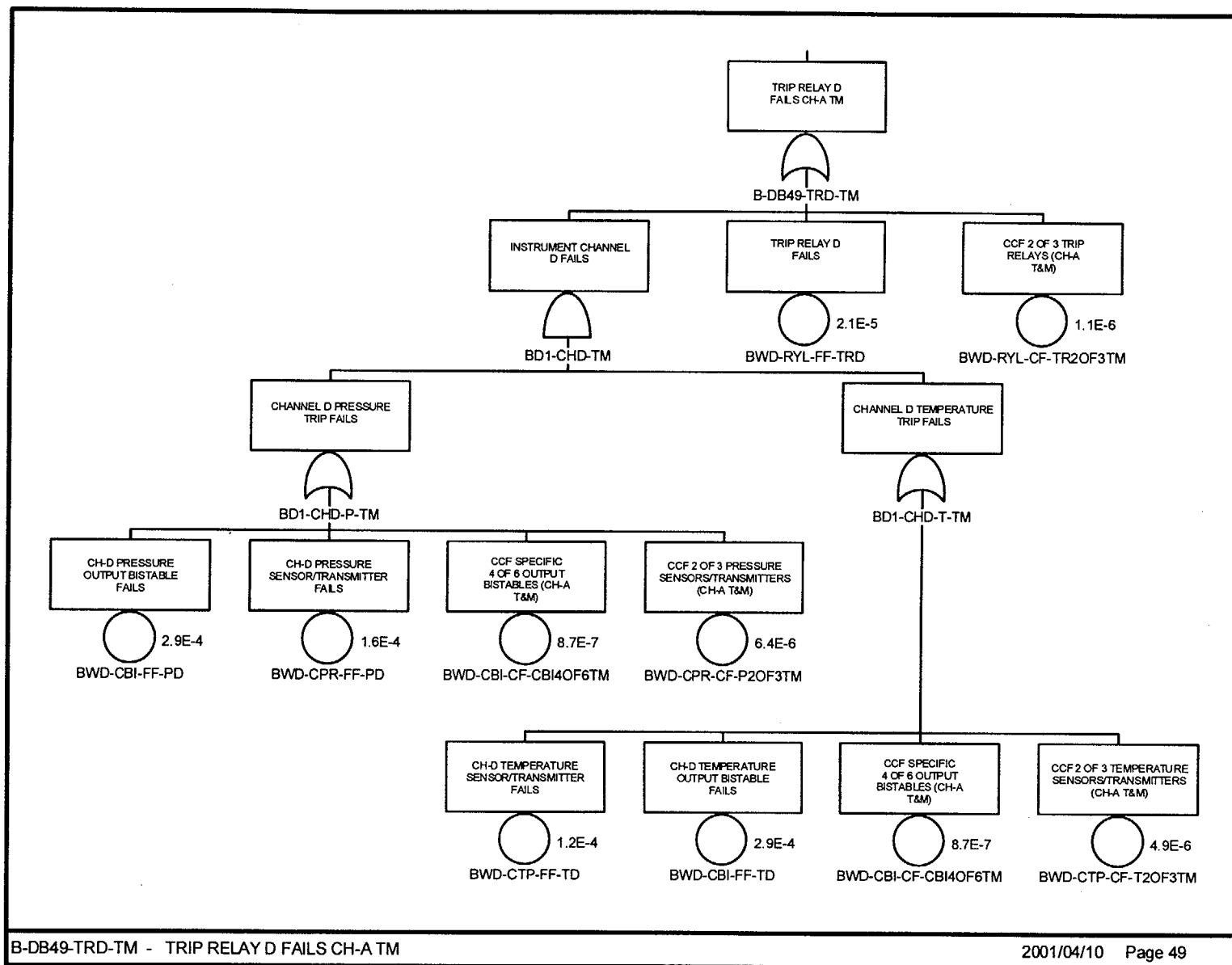






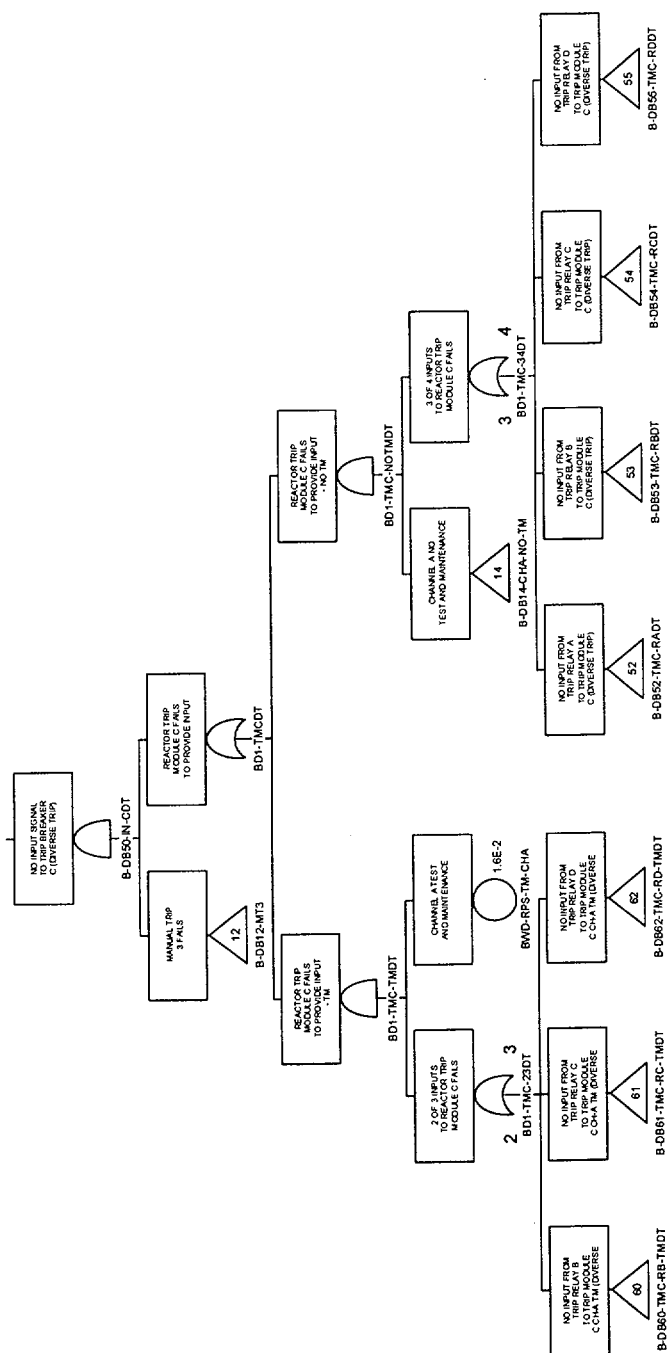




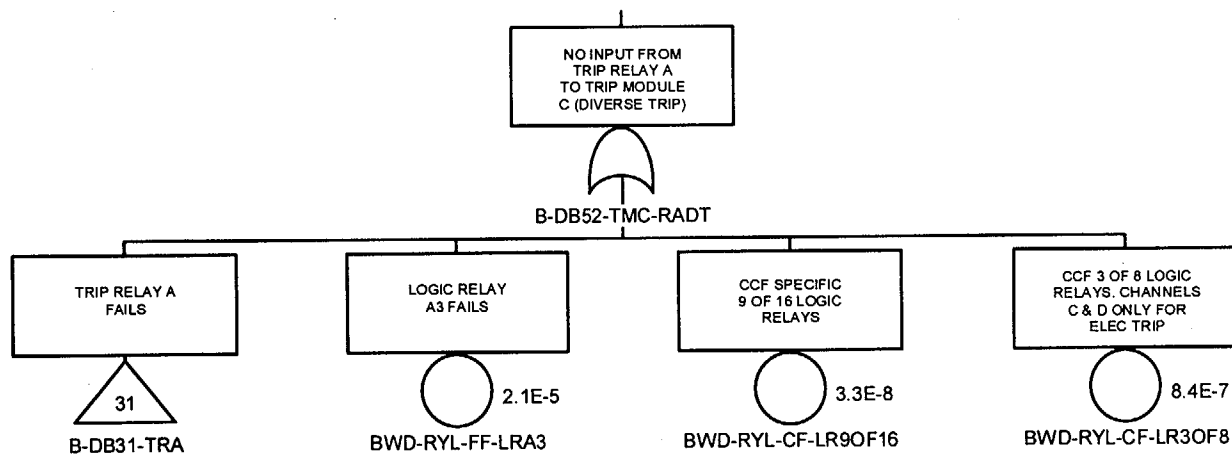


B-DB49-TRD-TM - TRIP RELAY D FAILS CH-A TM

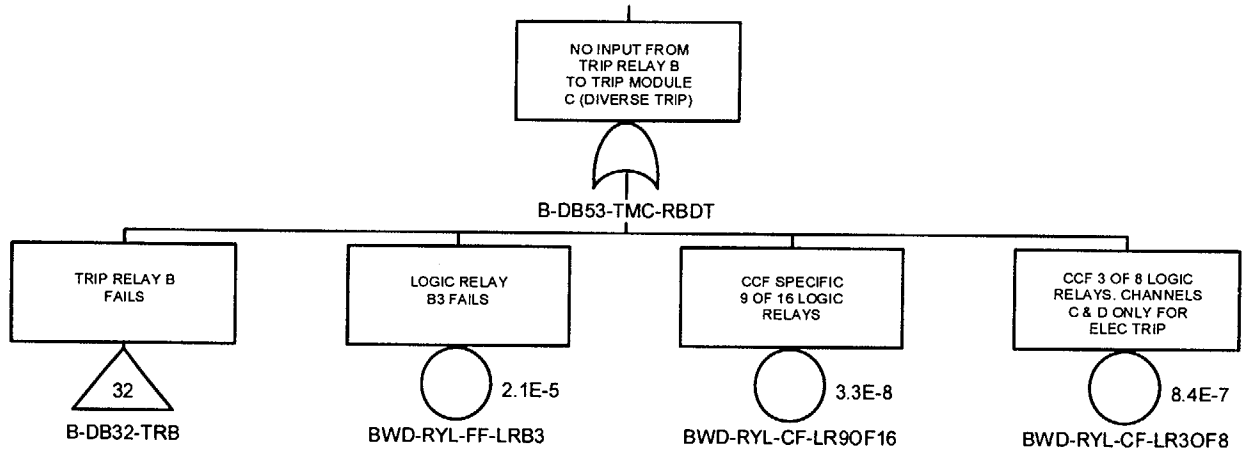
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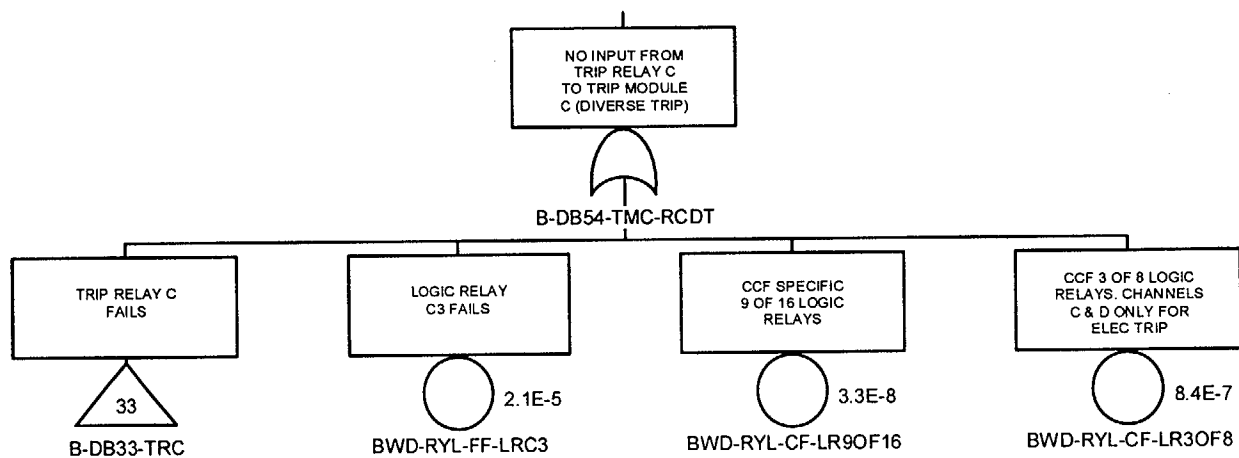




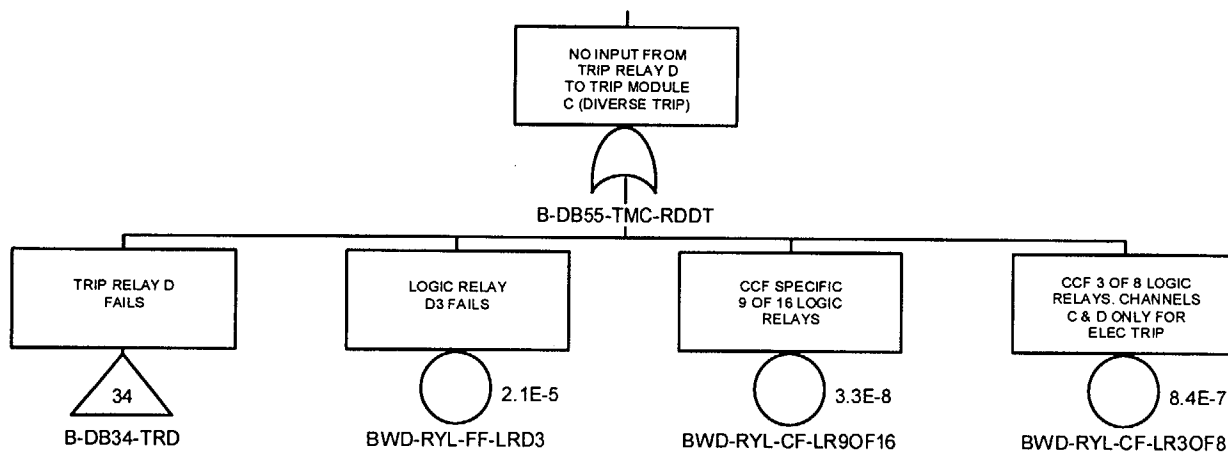


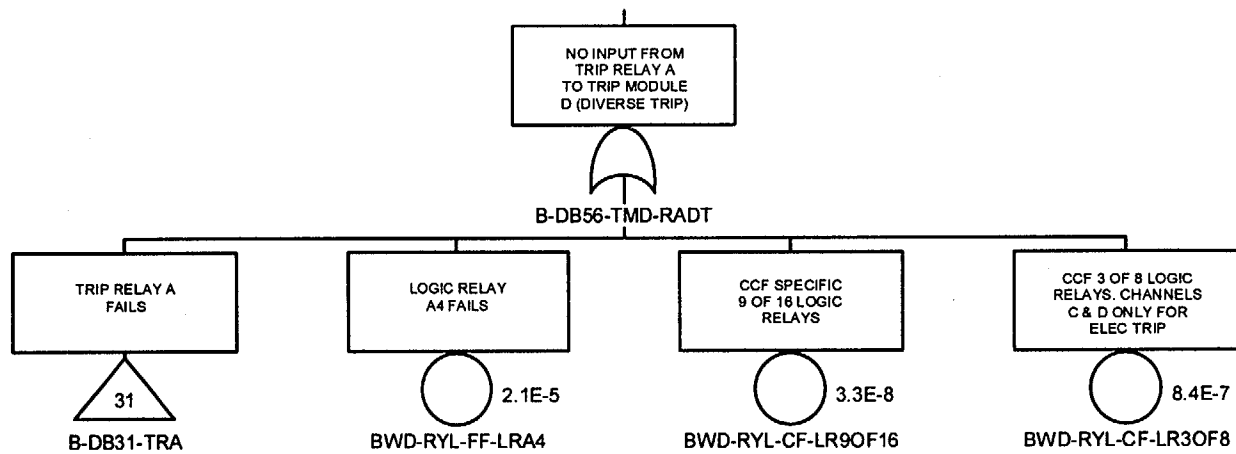
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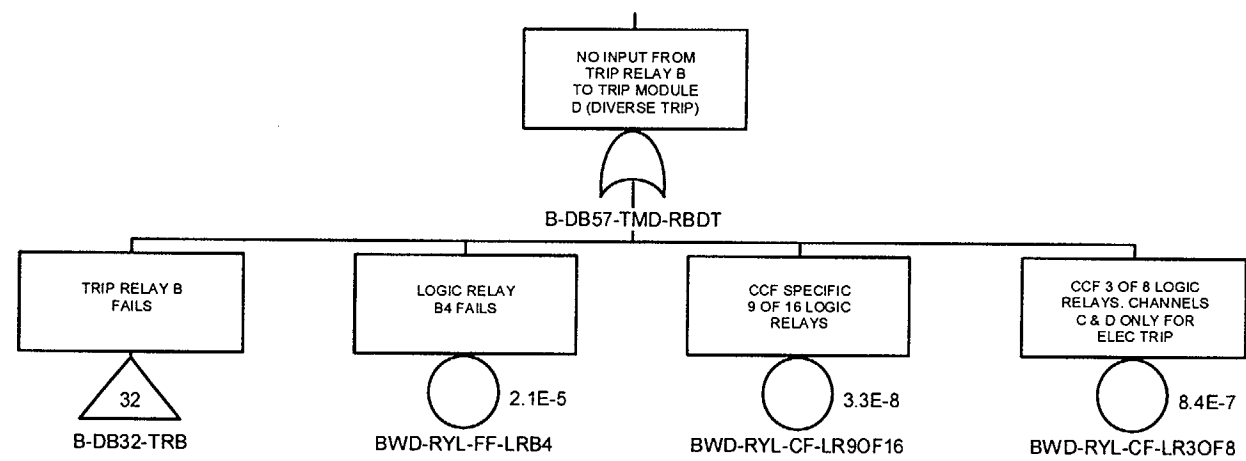


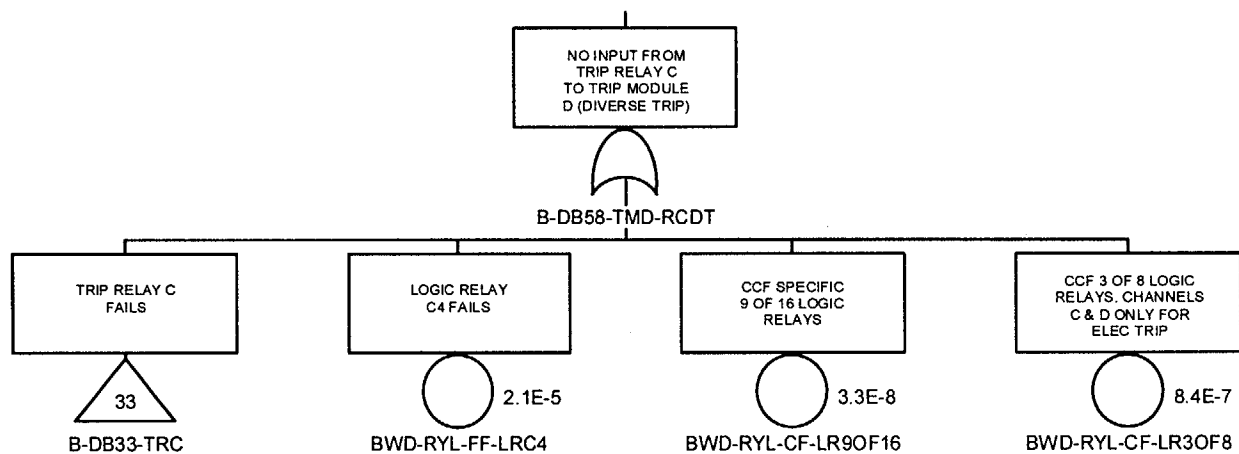
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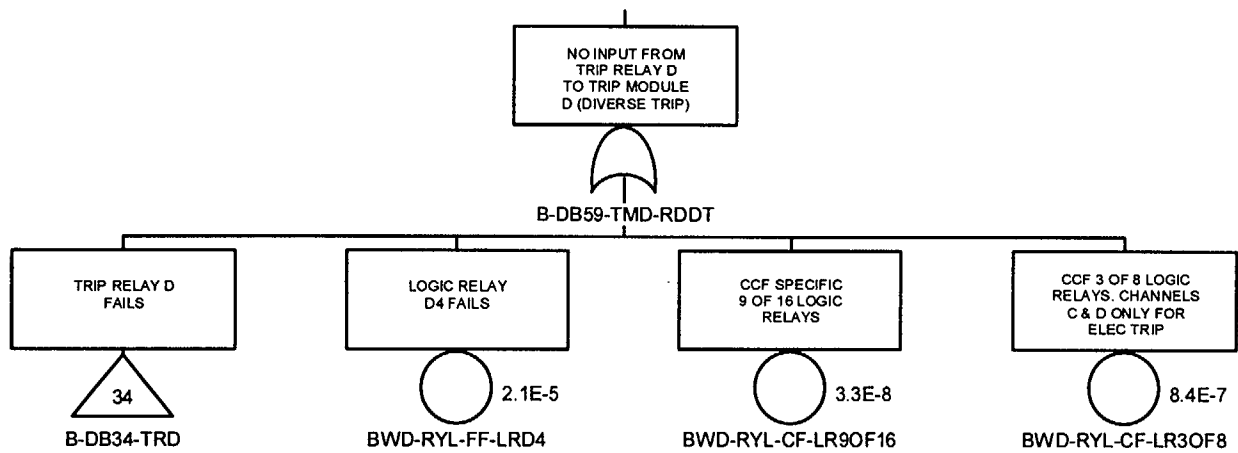


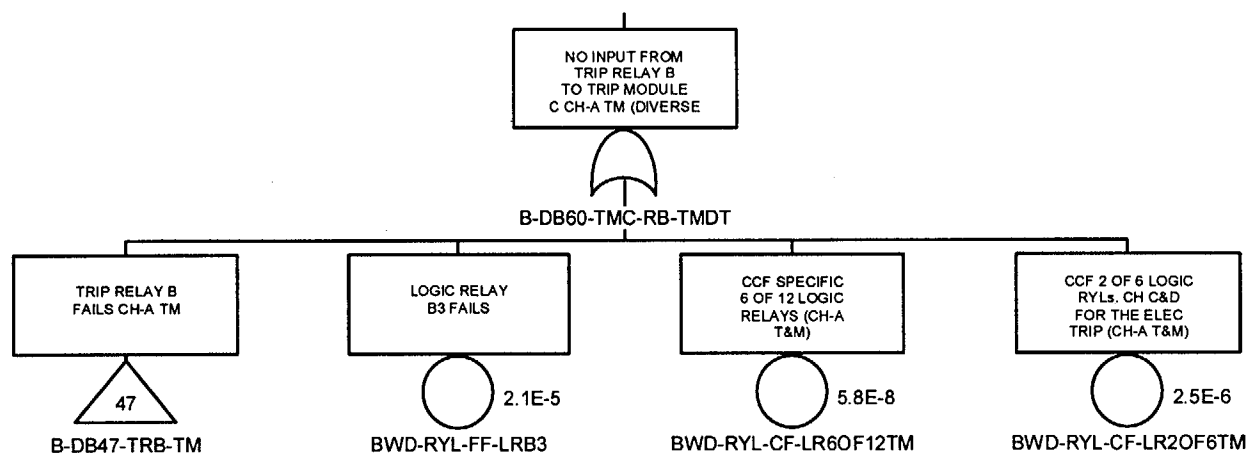
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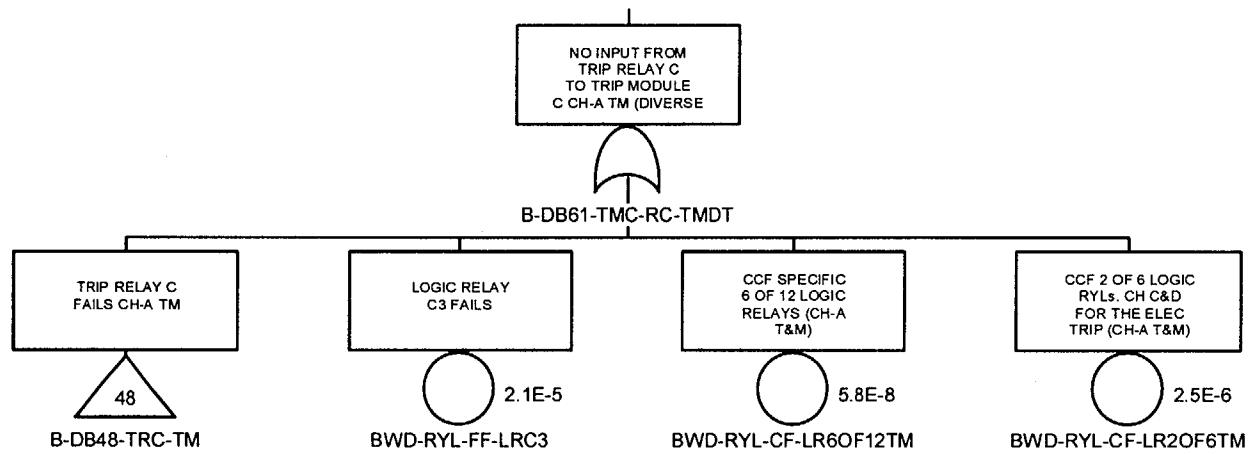


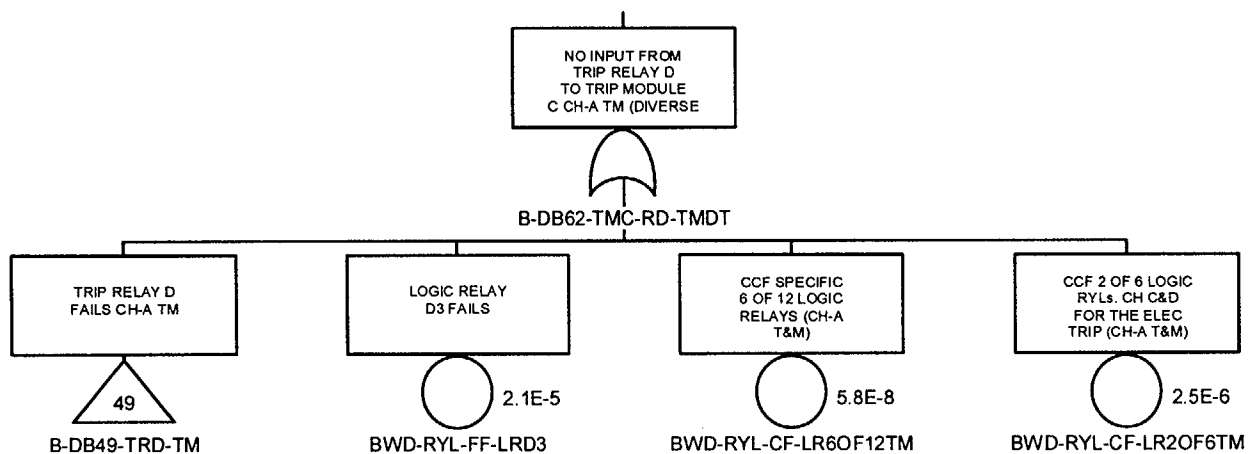
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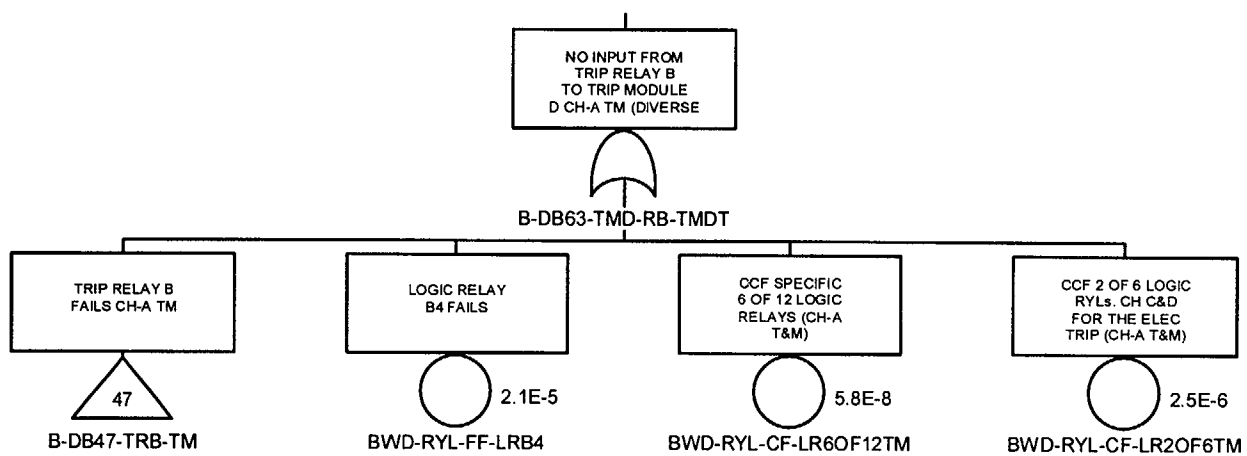


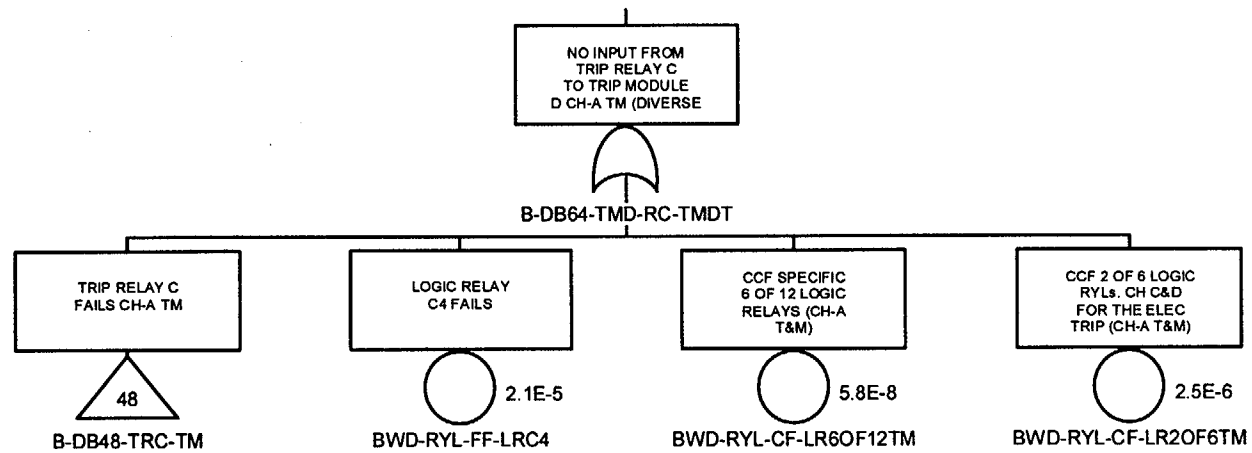


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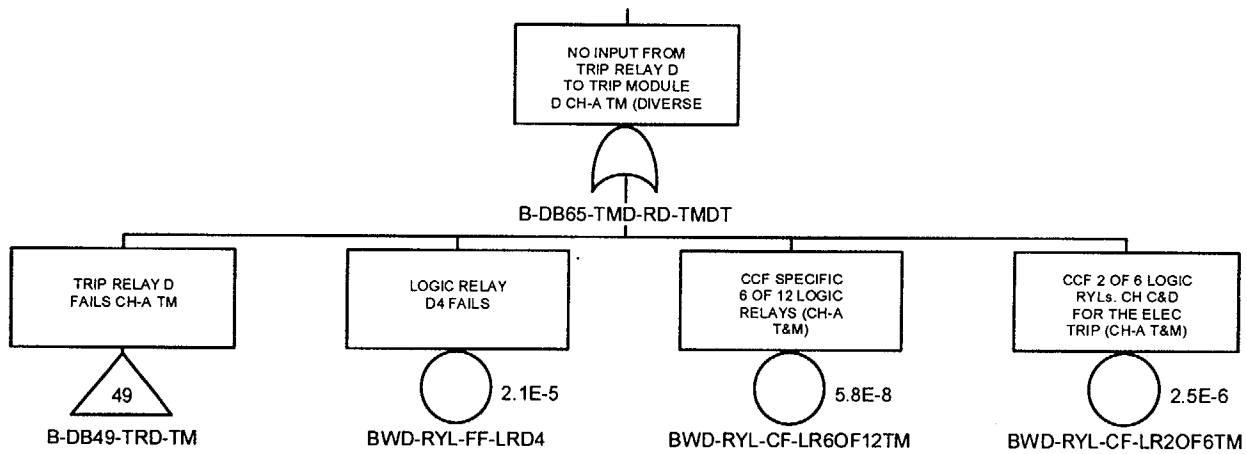




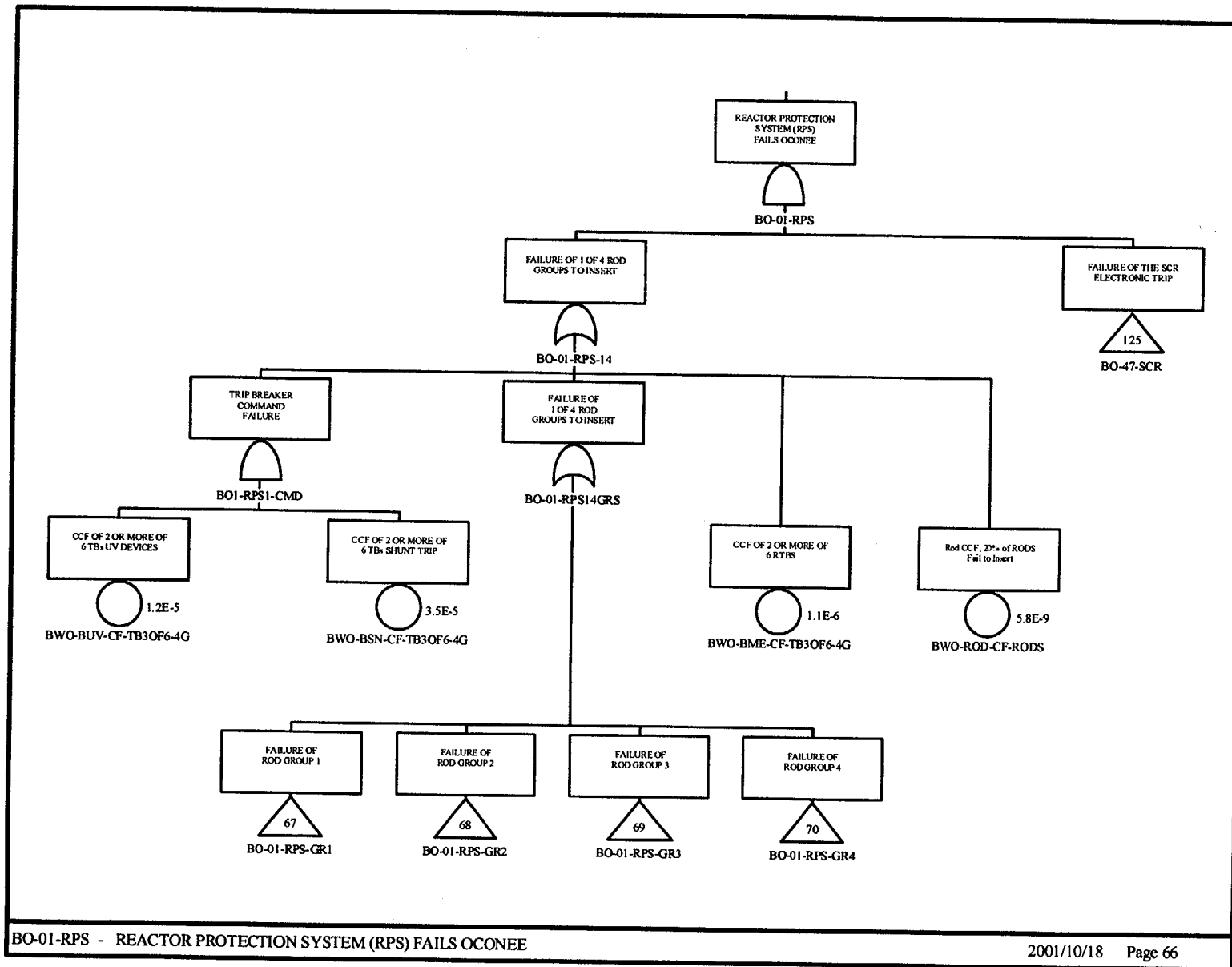


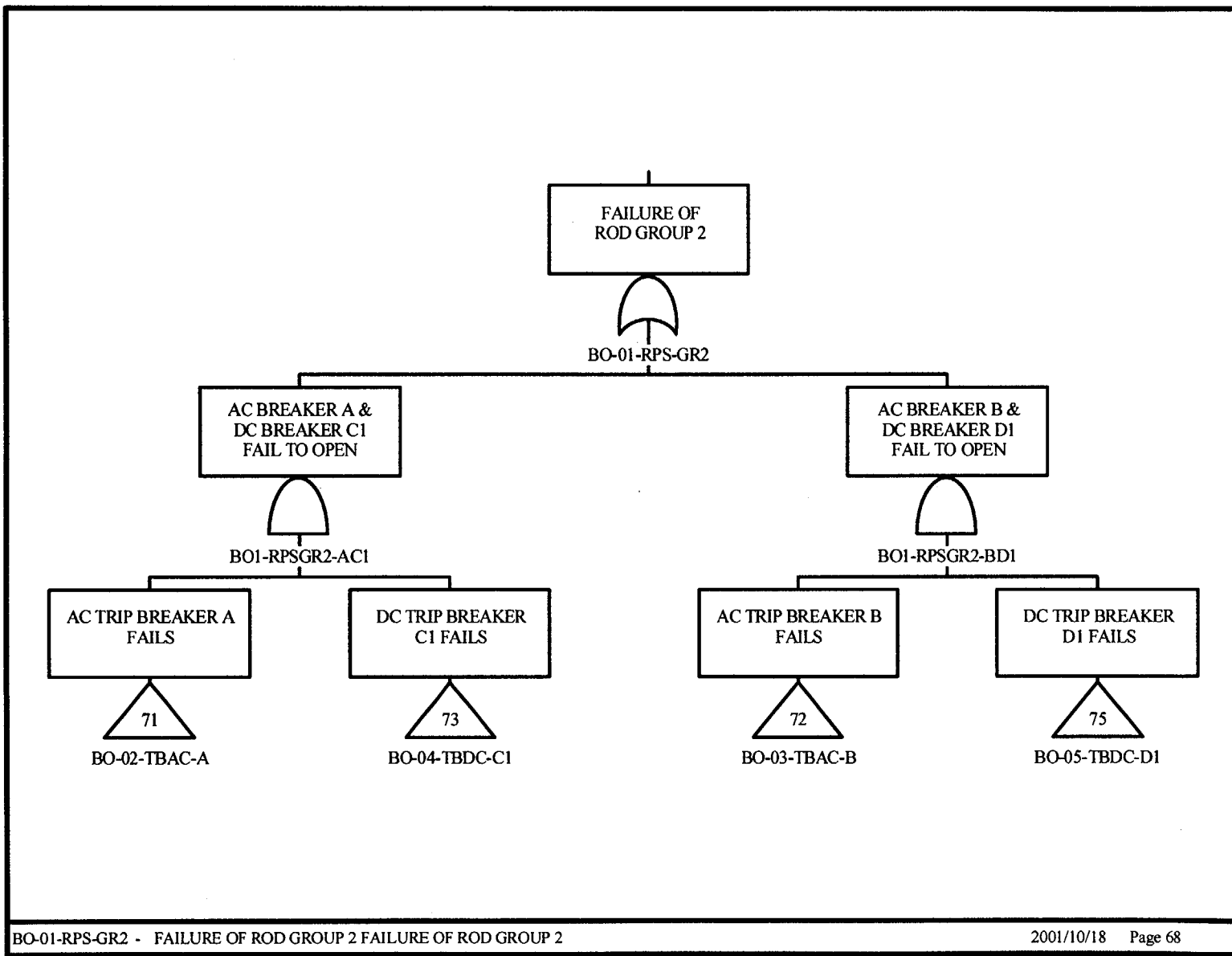


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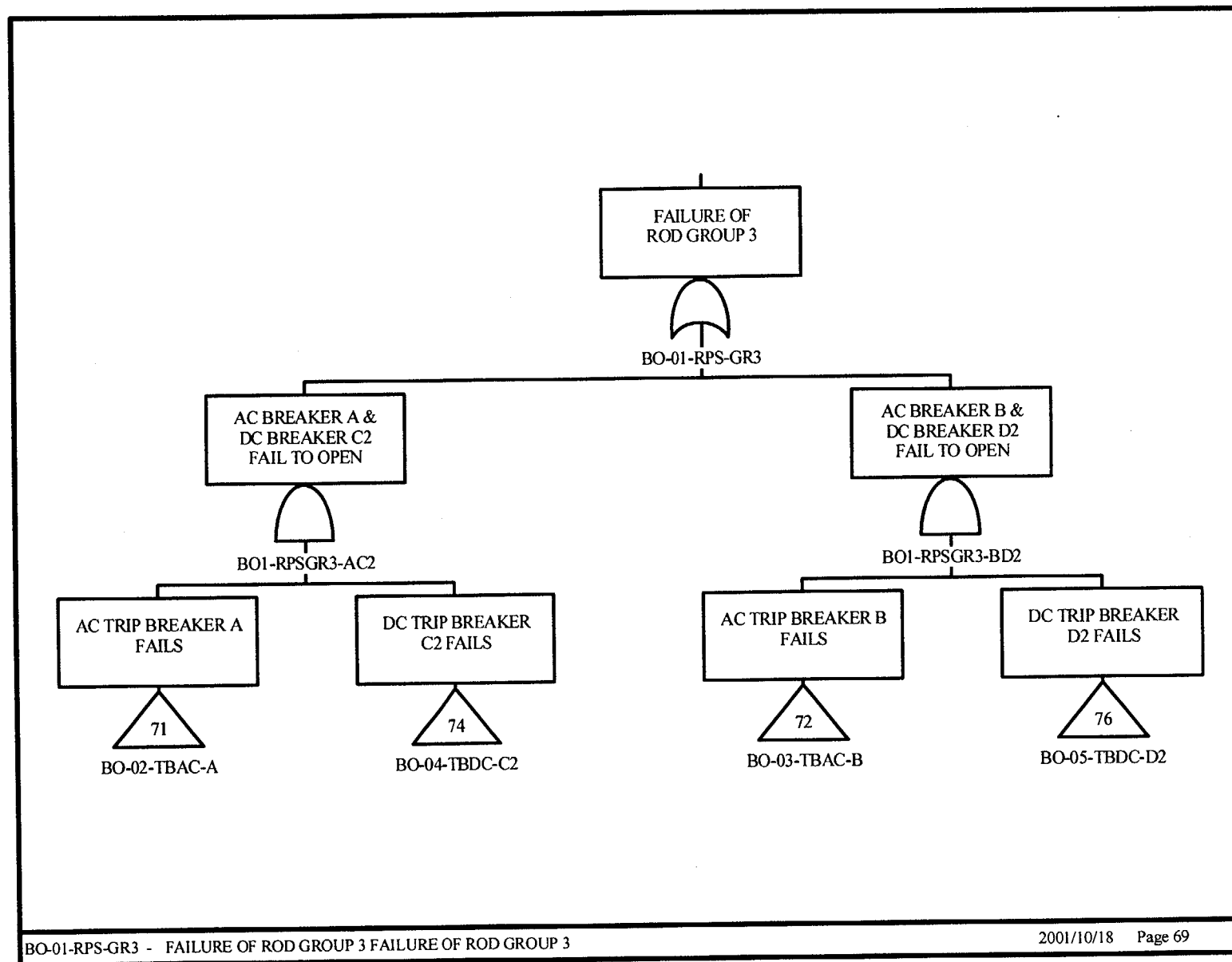


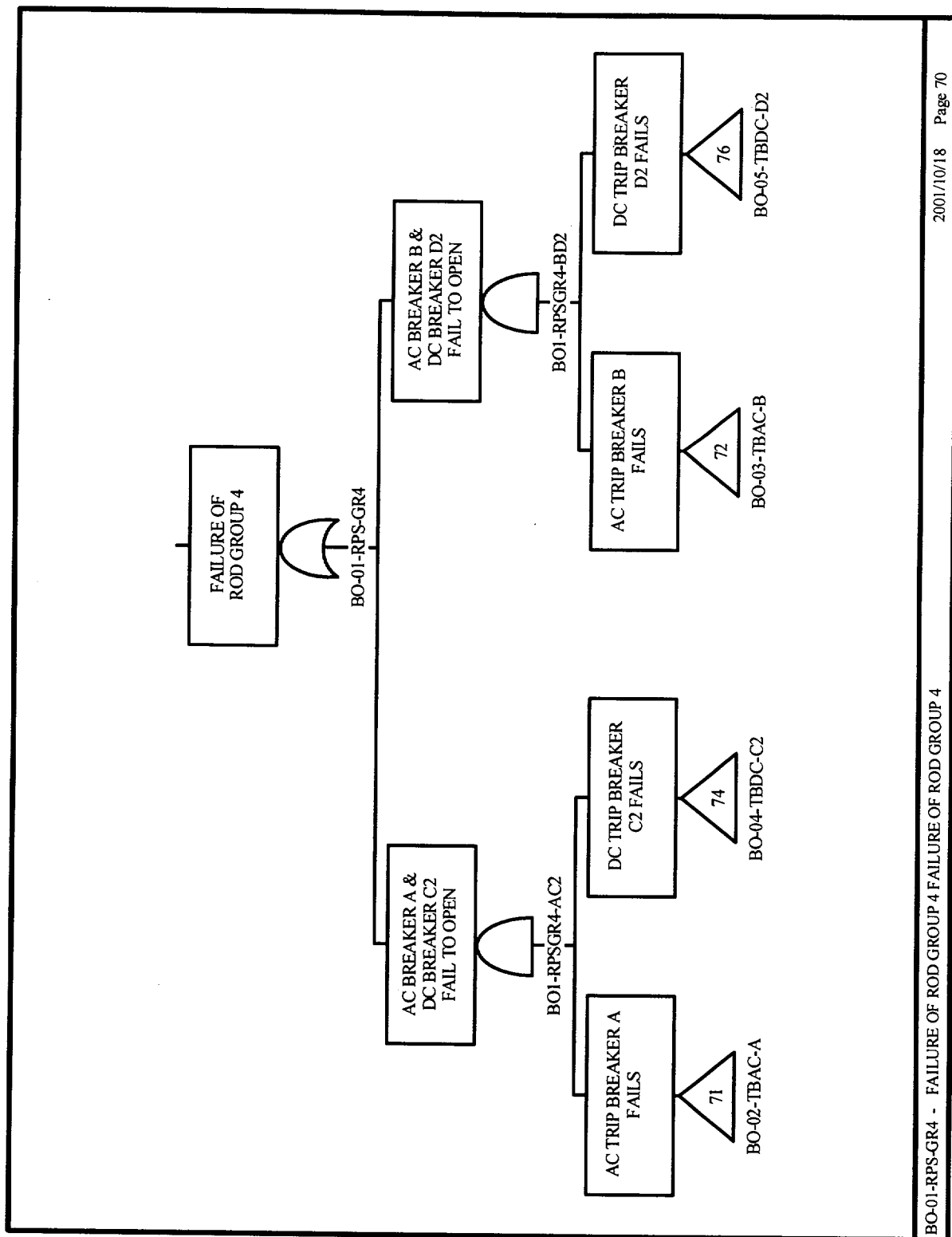
OCONEE MODEL





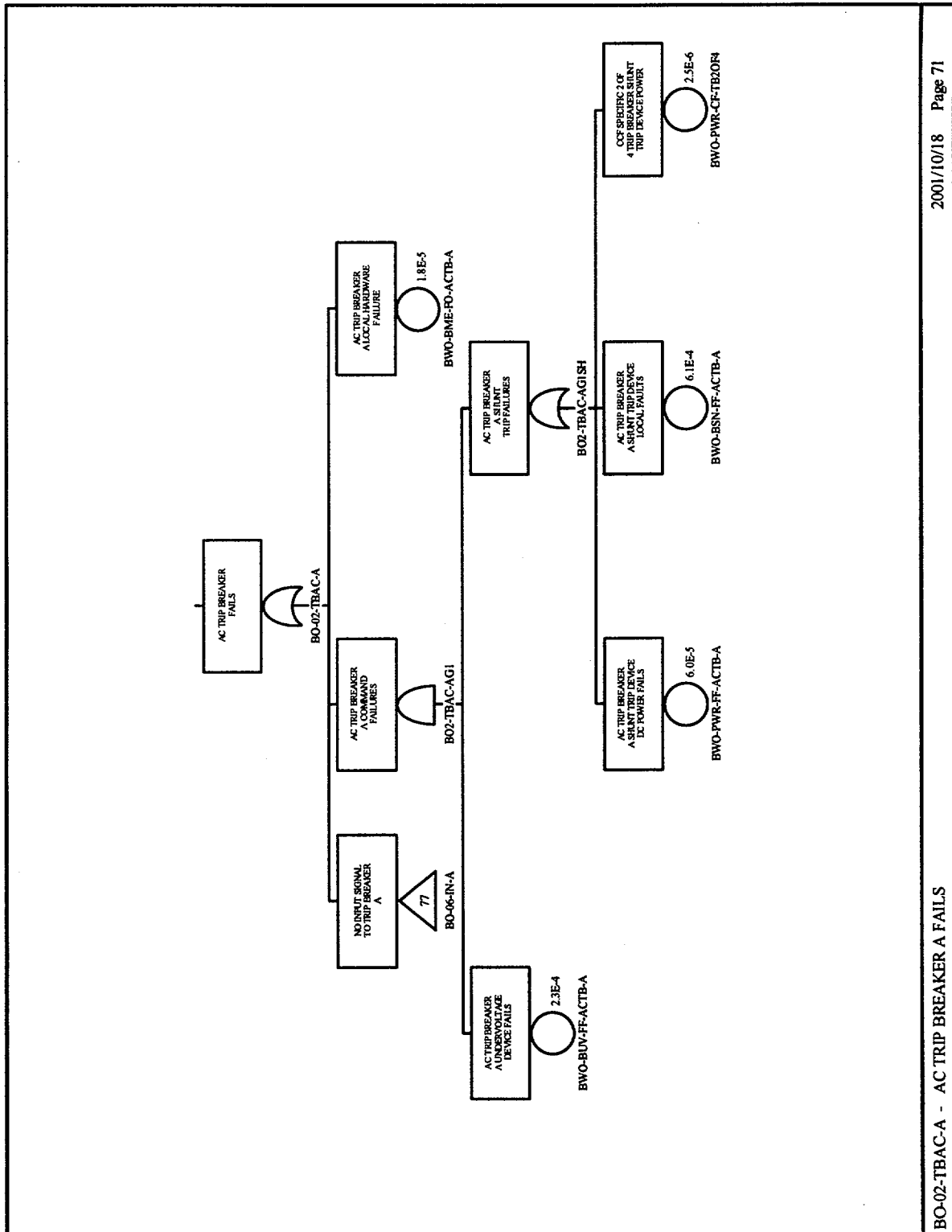
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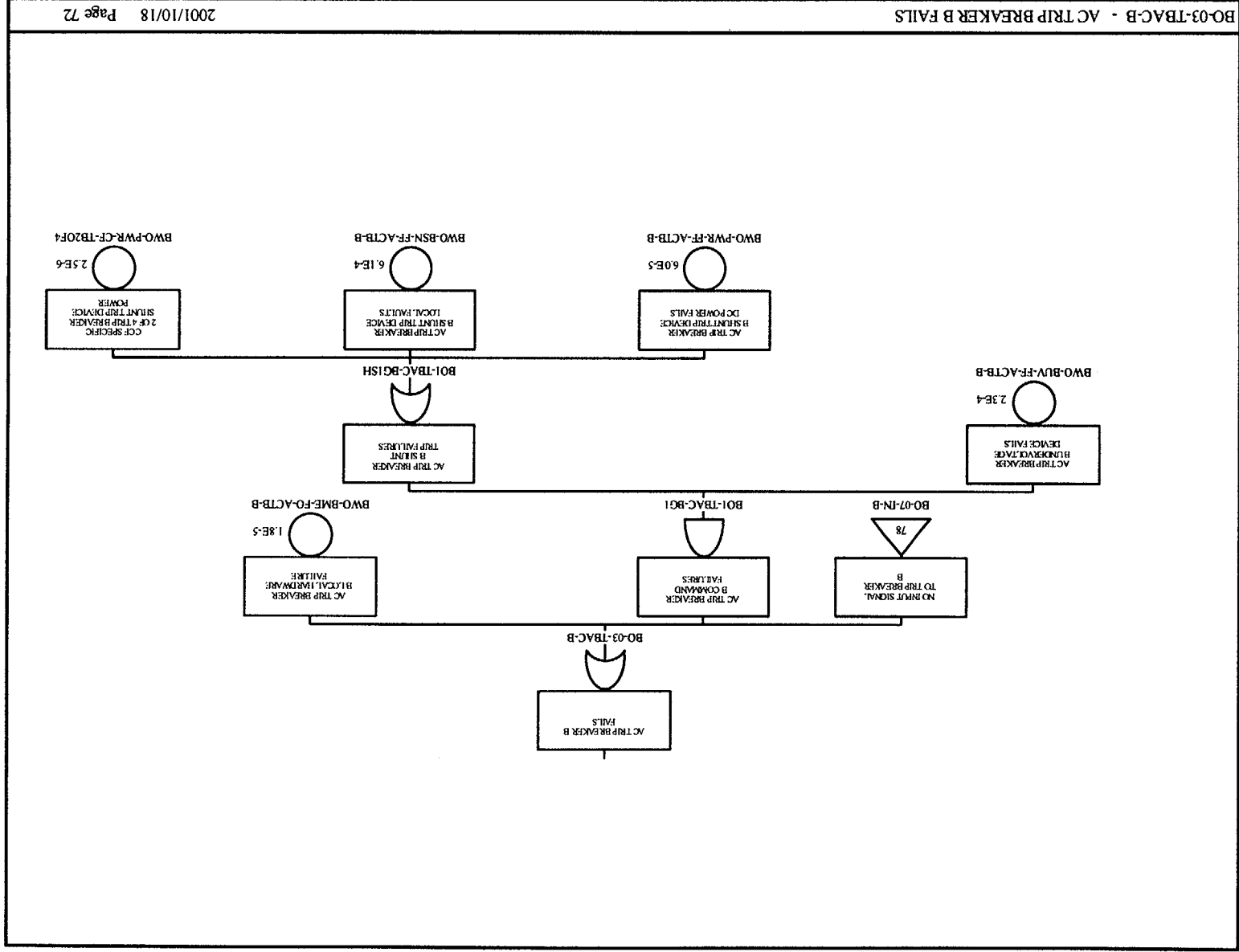


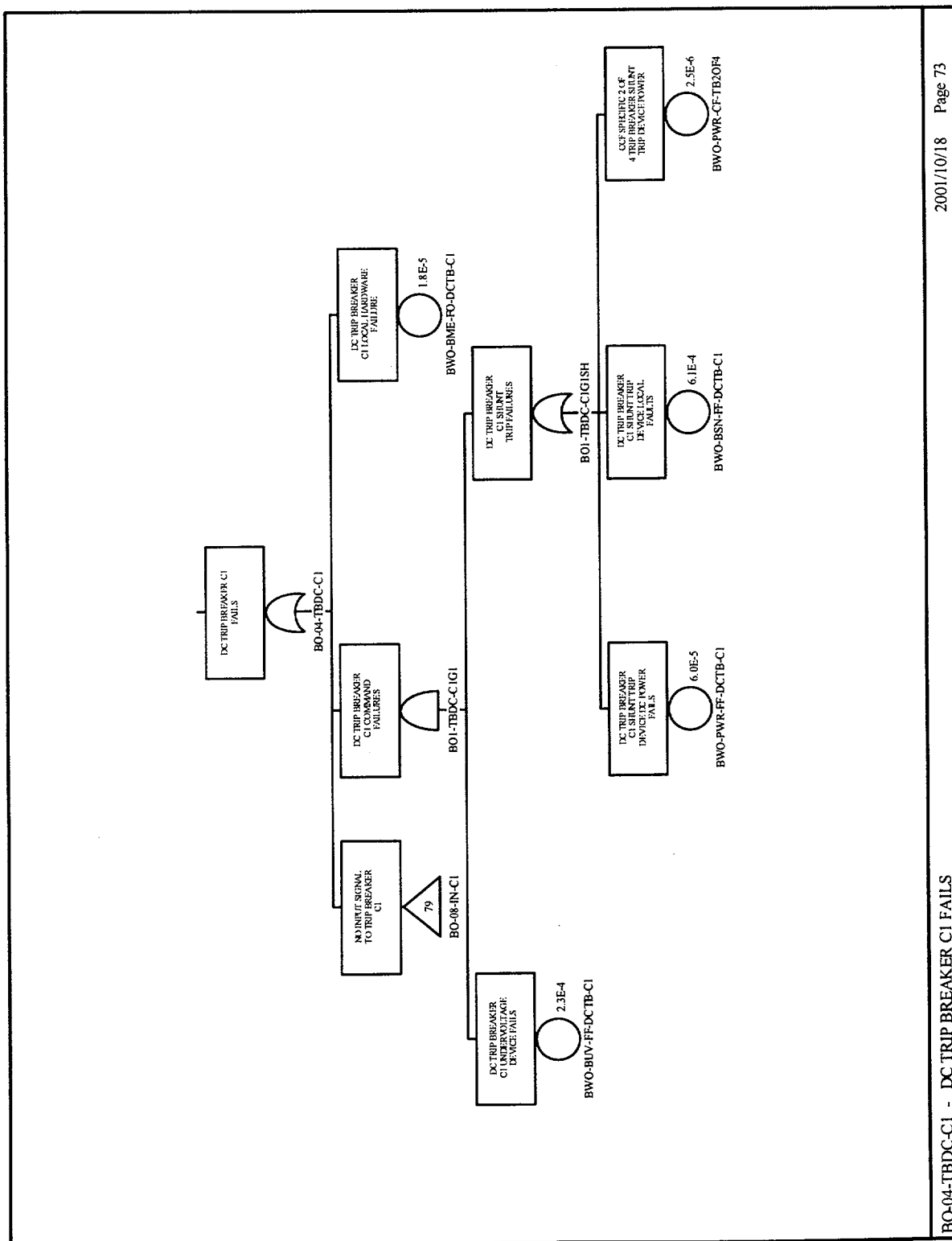


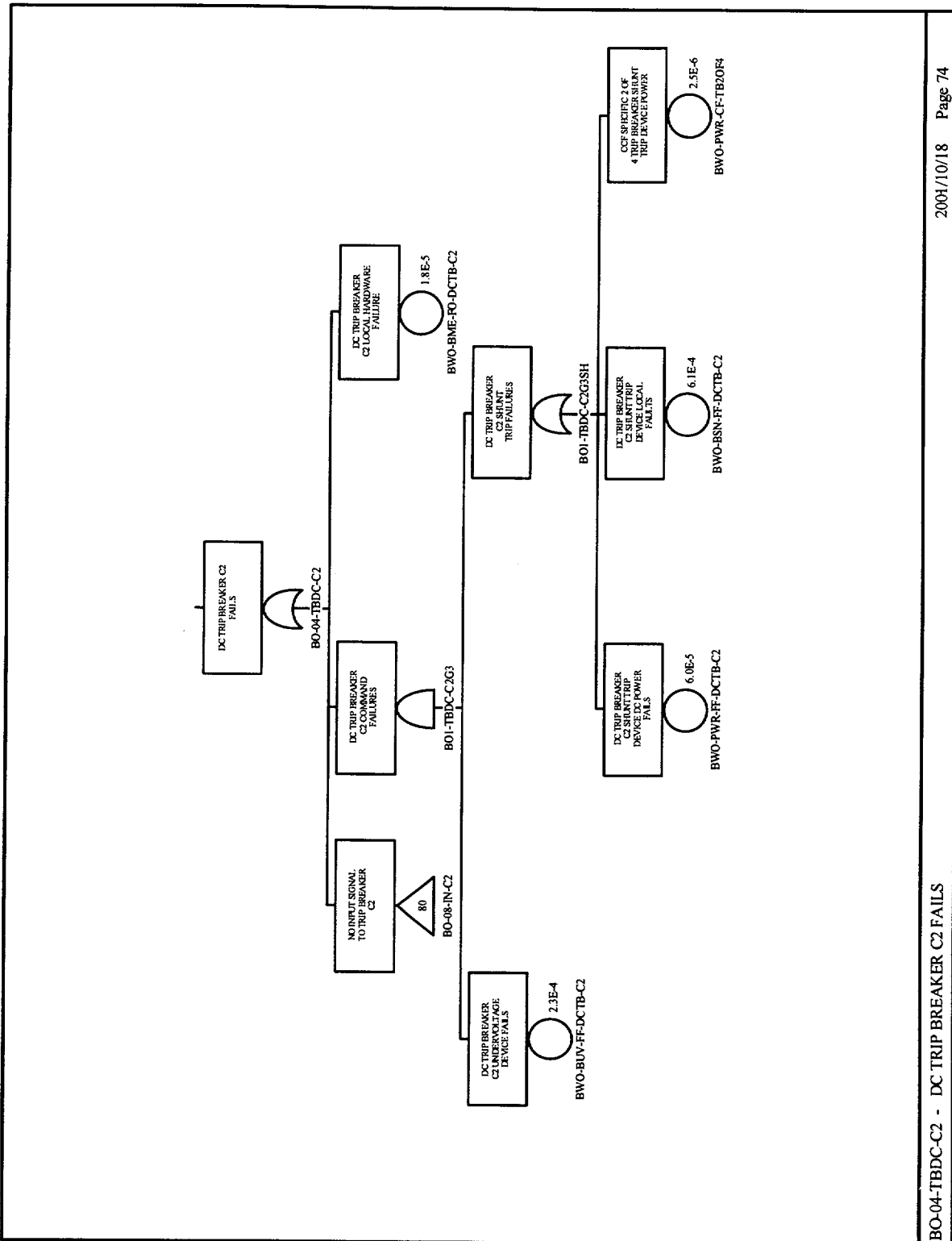
BO-01-RPS-GR4 - FAILURE OF ROD GROUP 4 FAILURE OF ROD GROUP 4

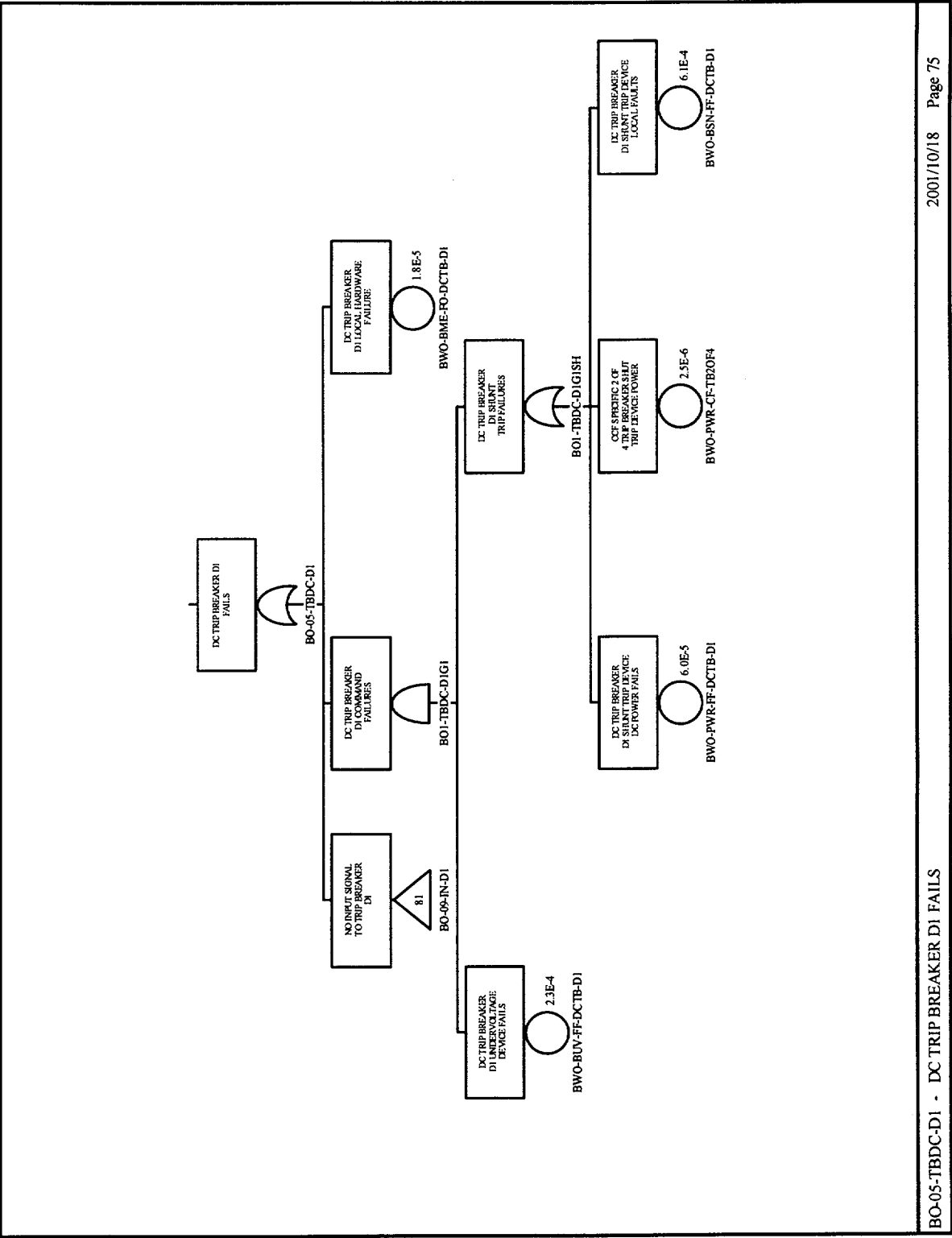
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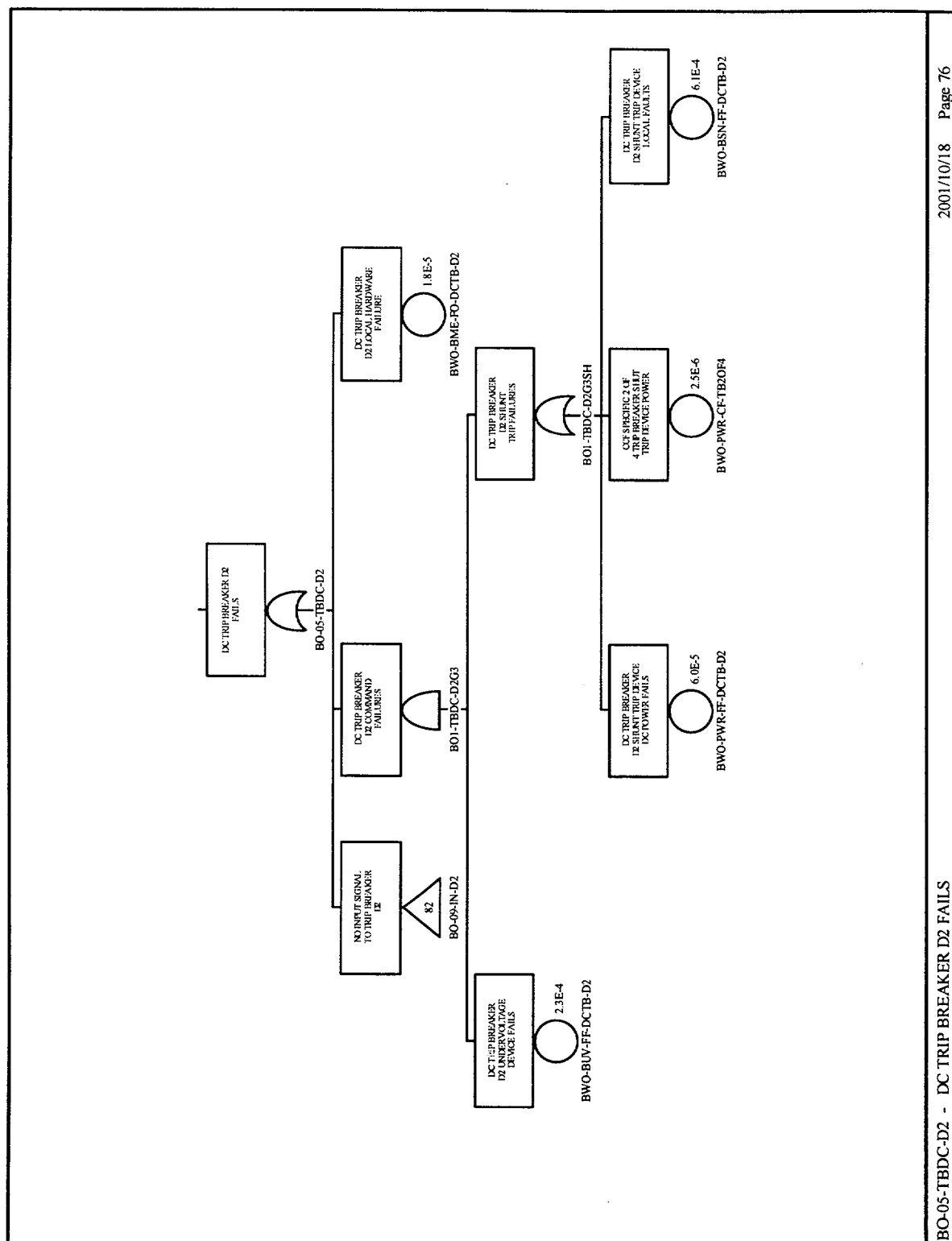


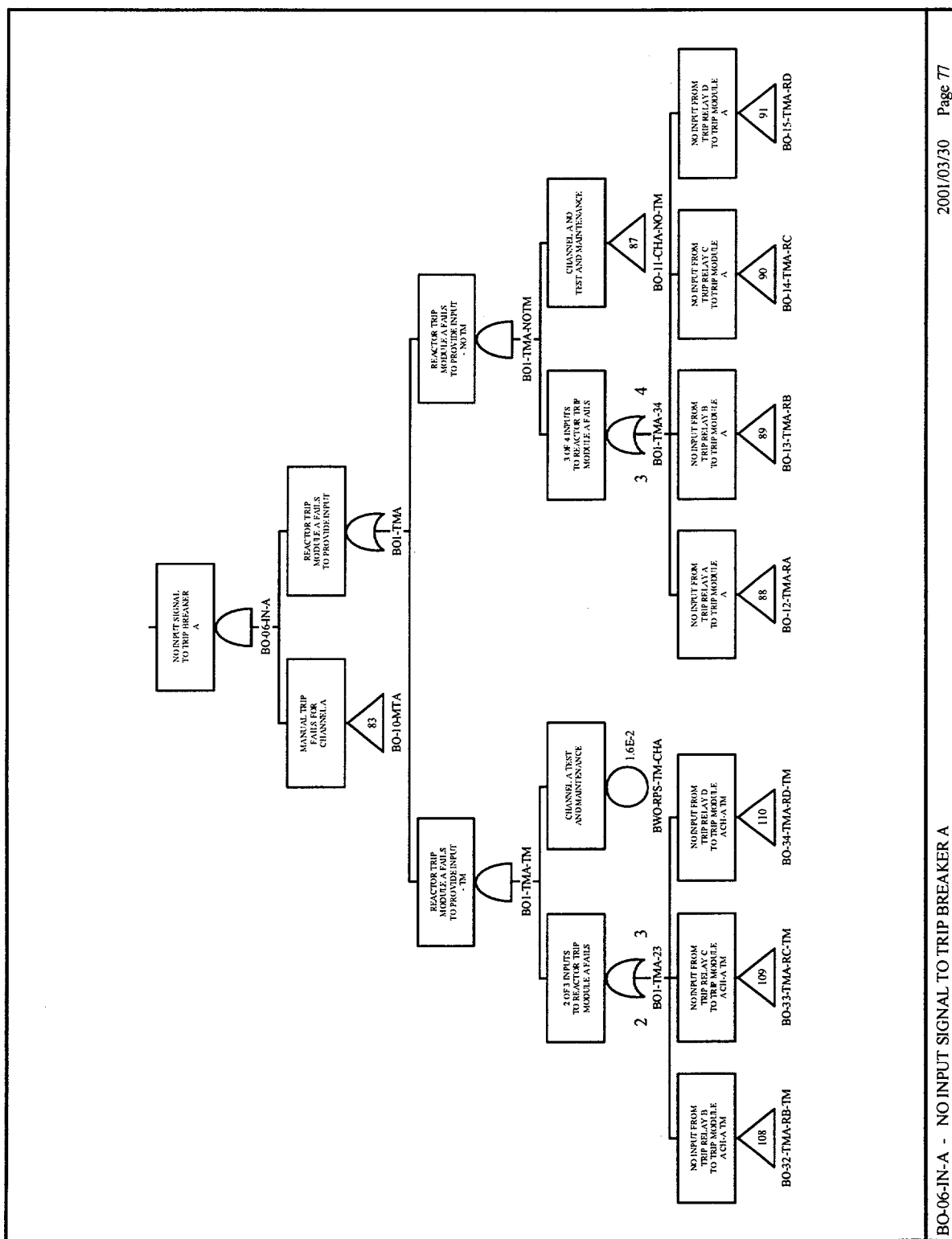


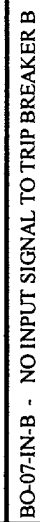


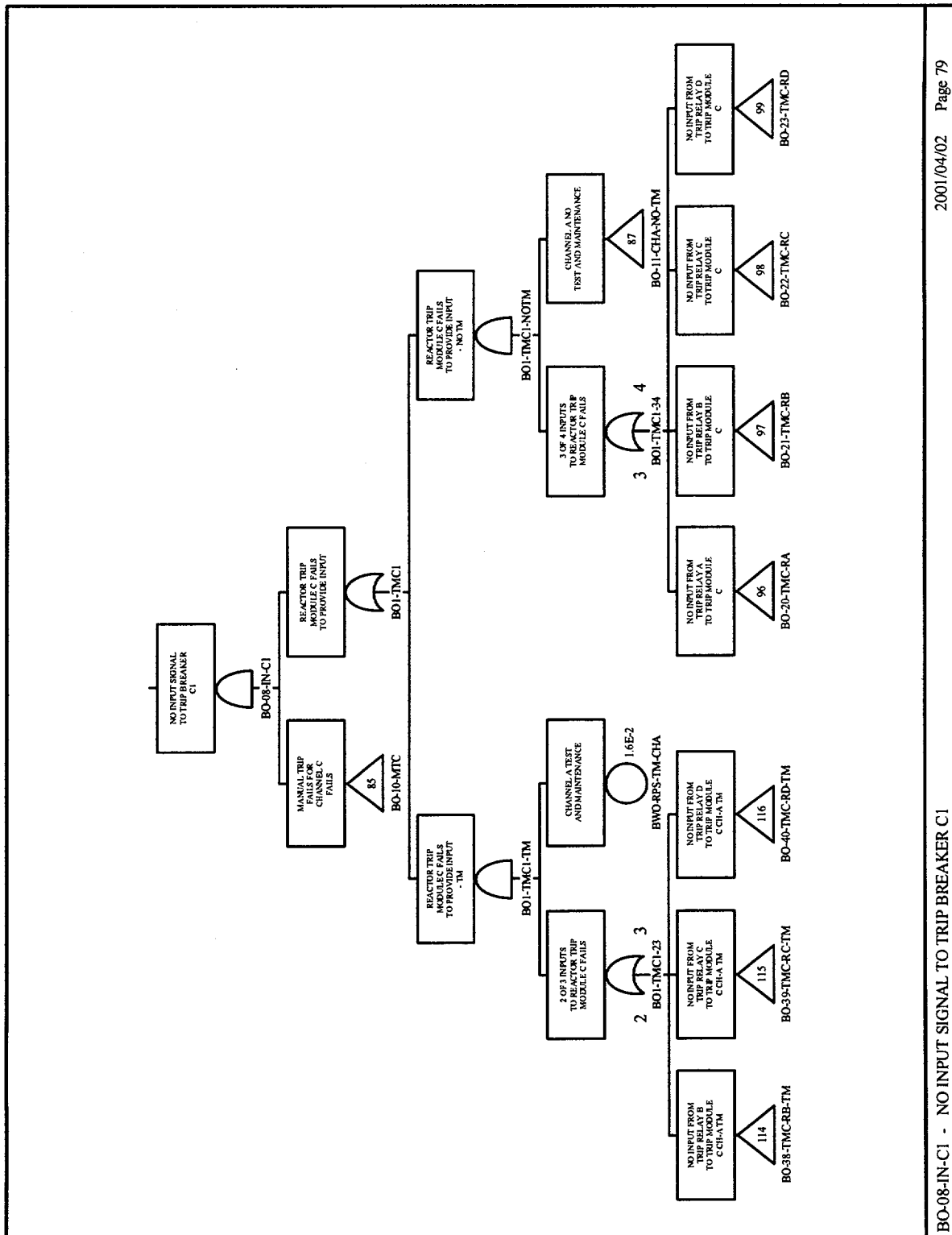


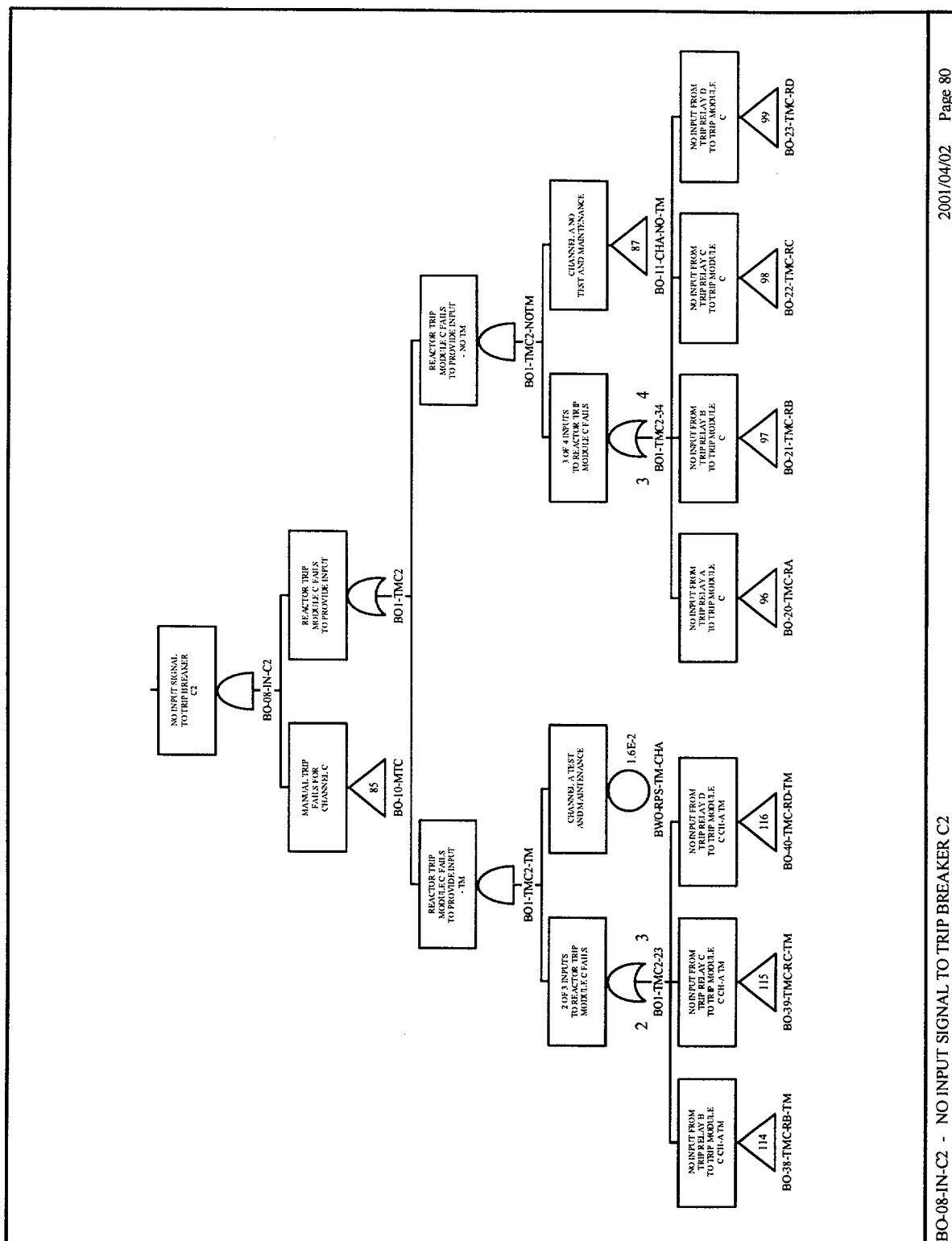


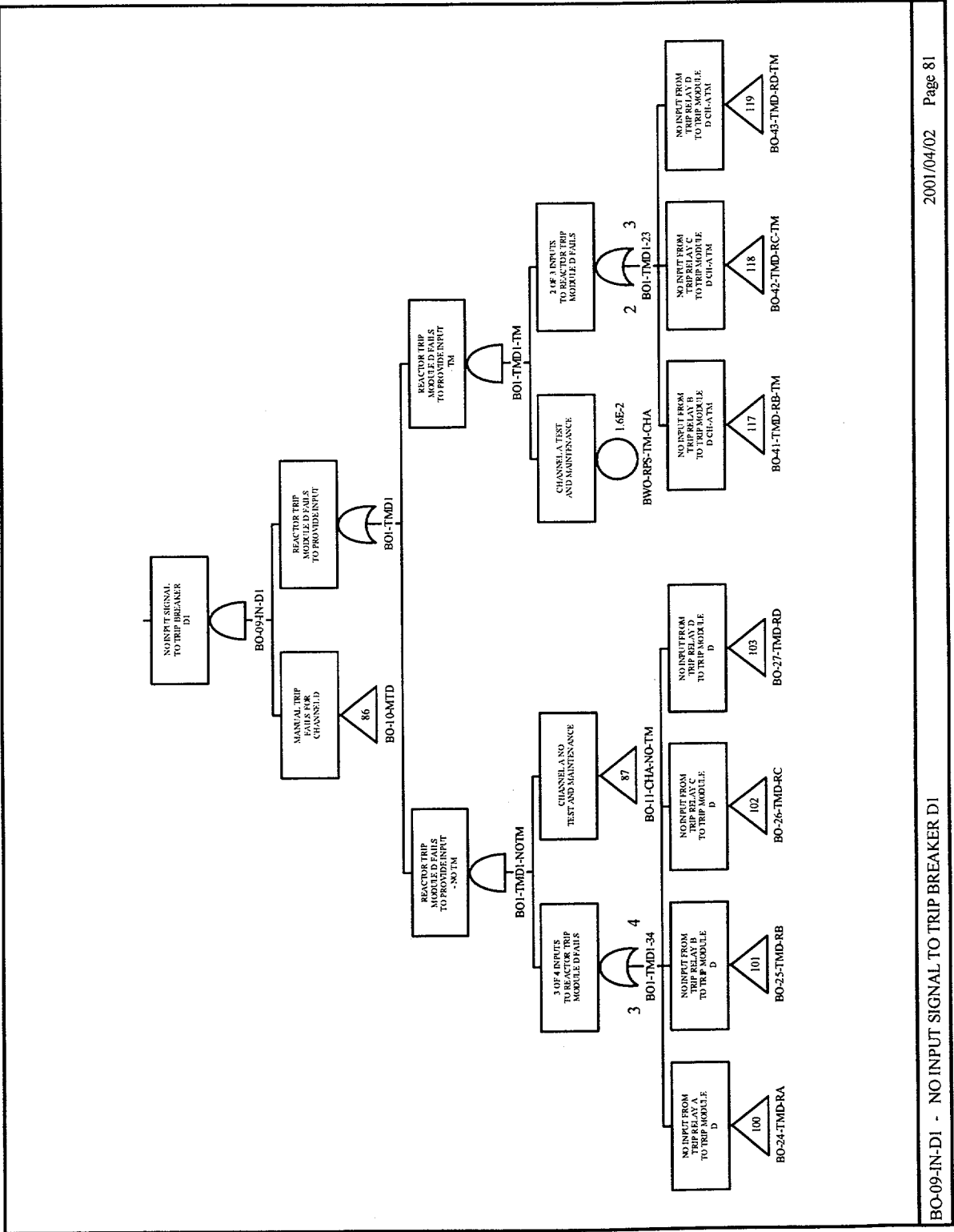


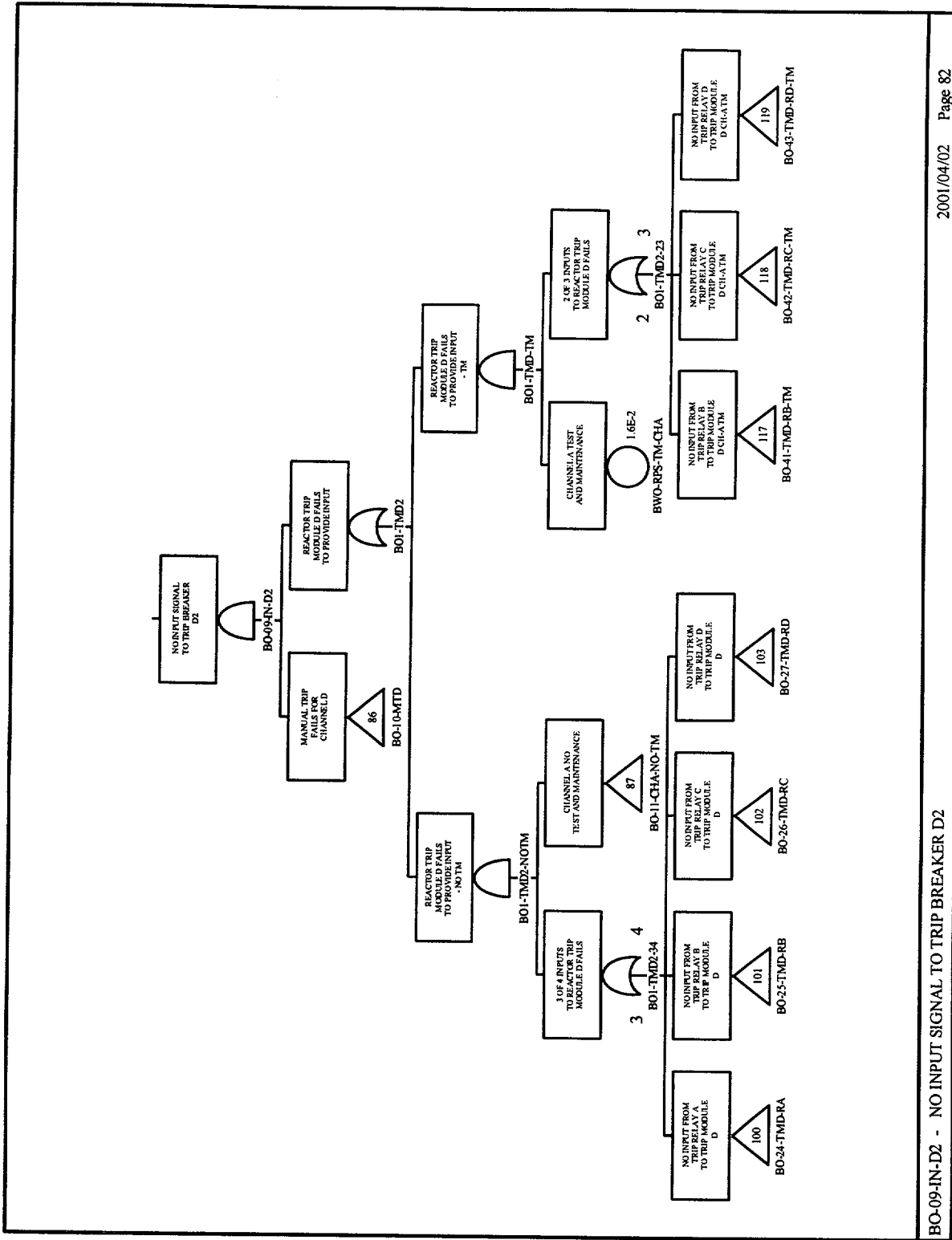


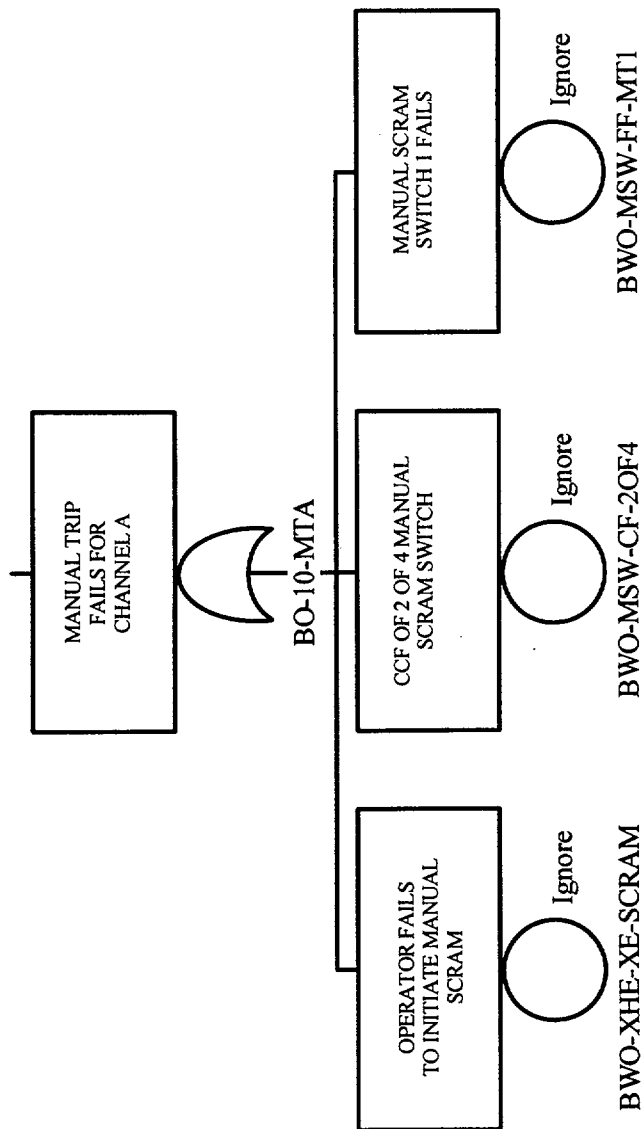


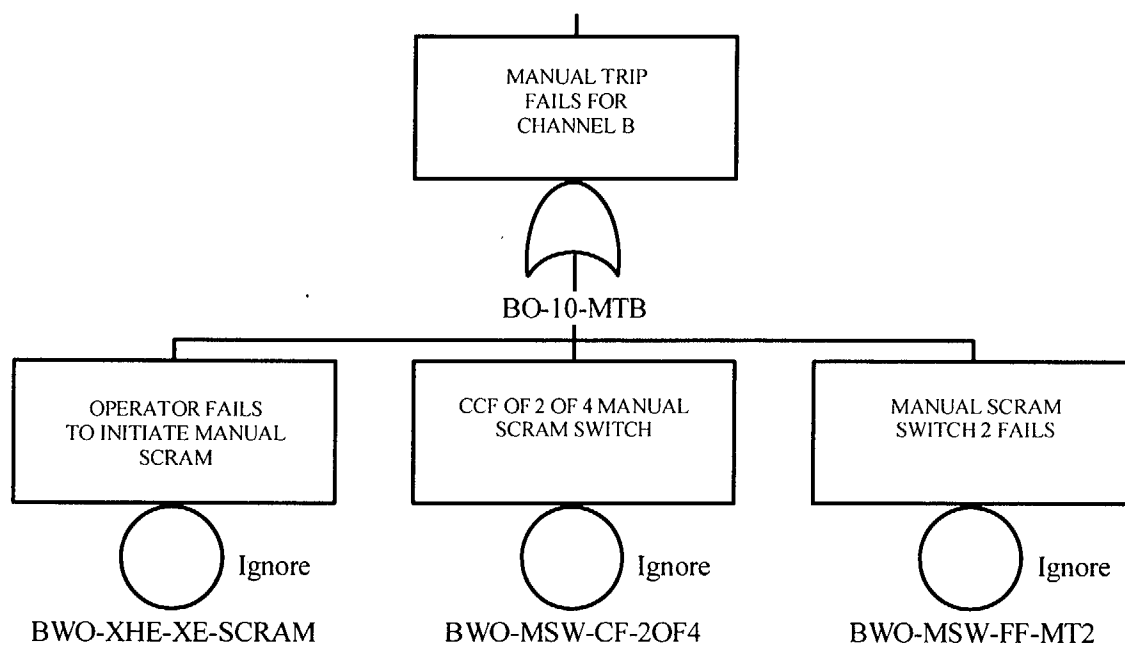




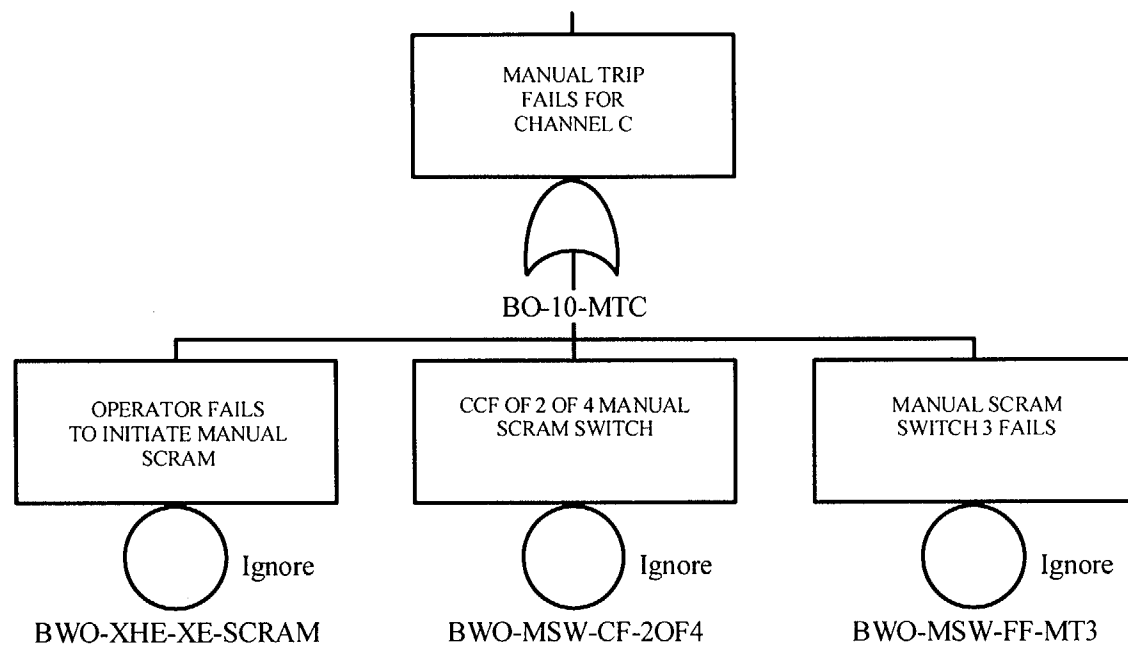


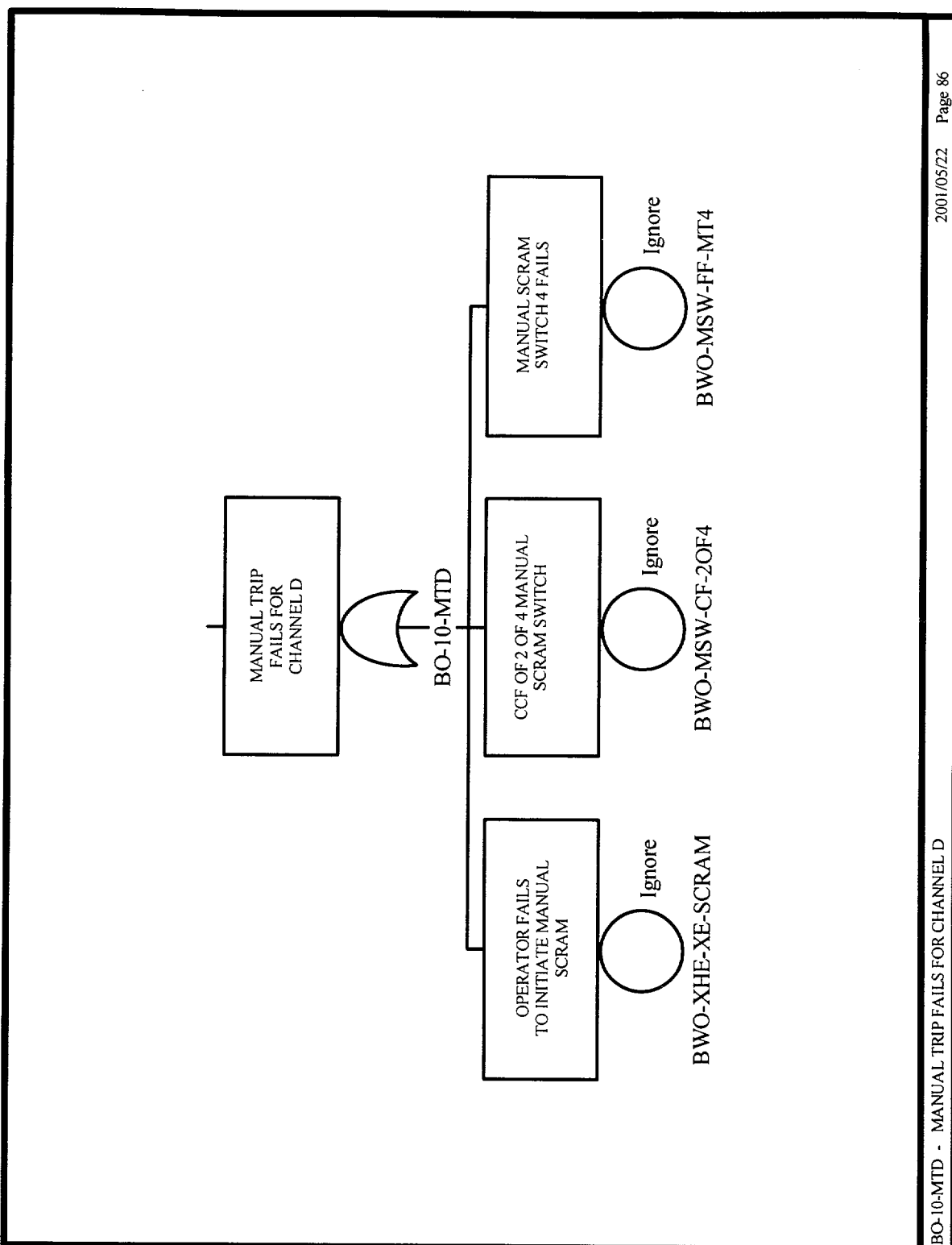


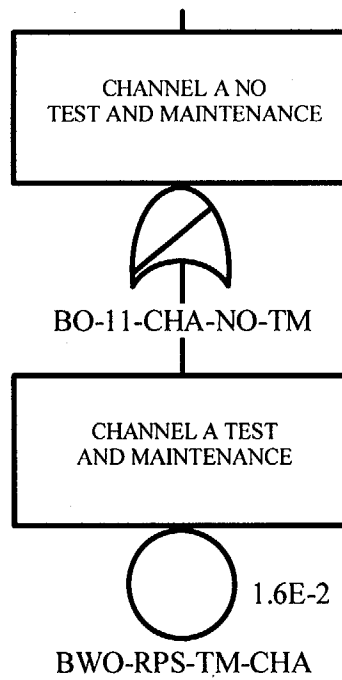




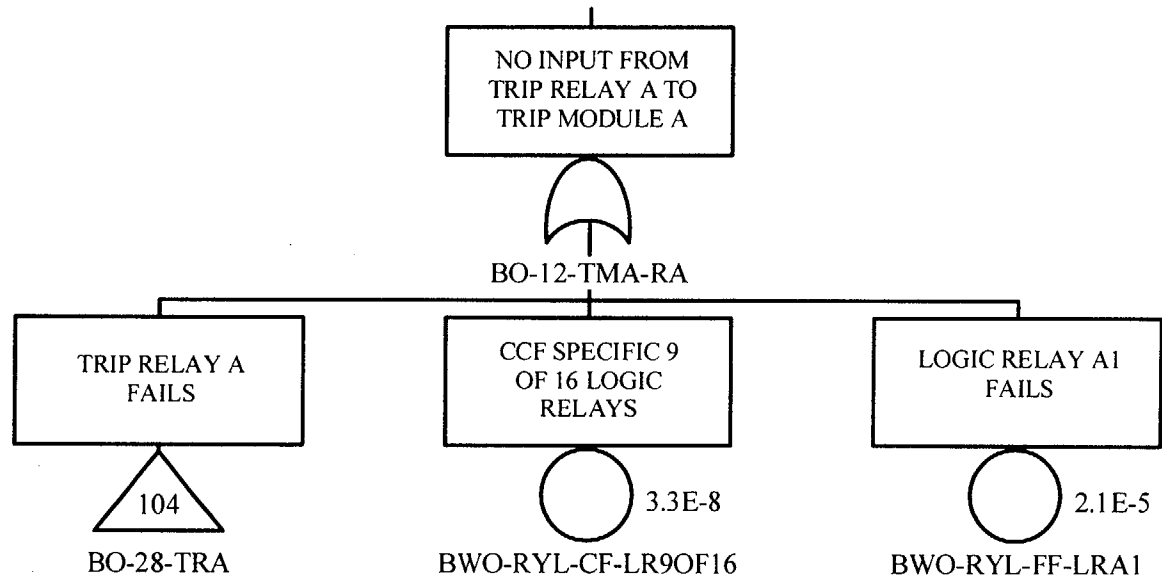
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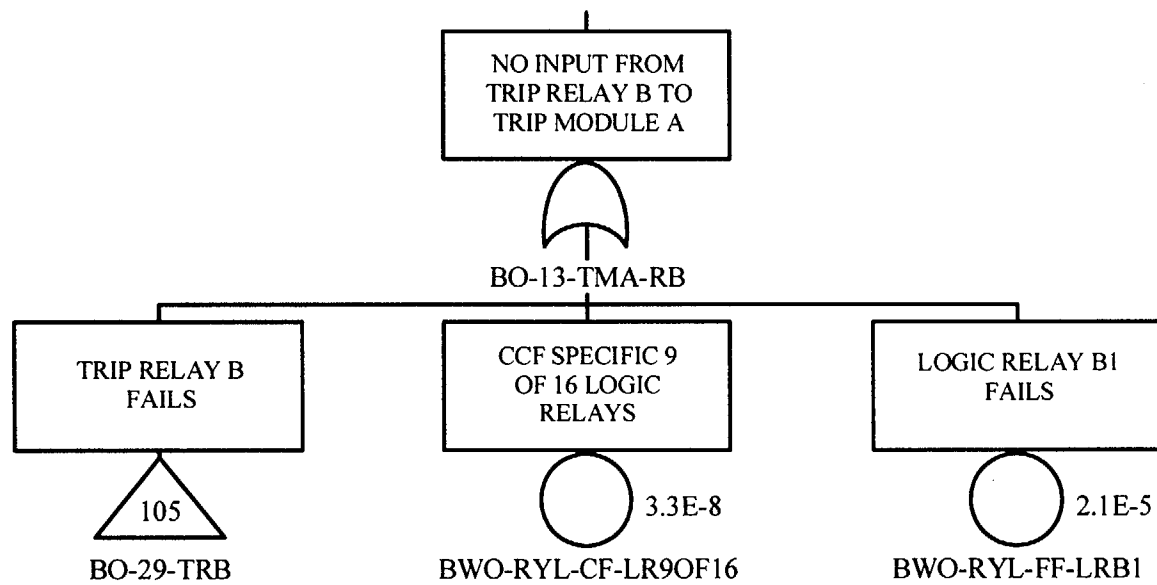


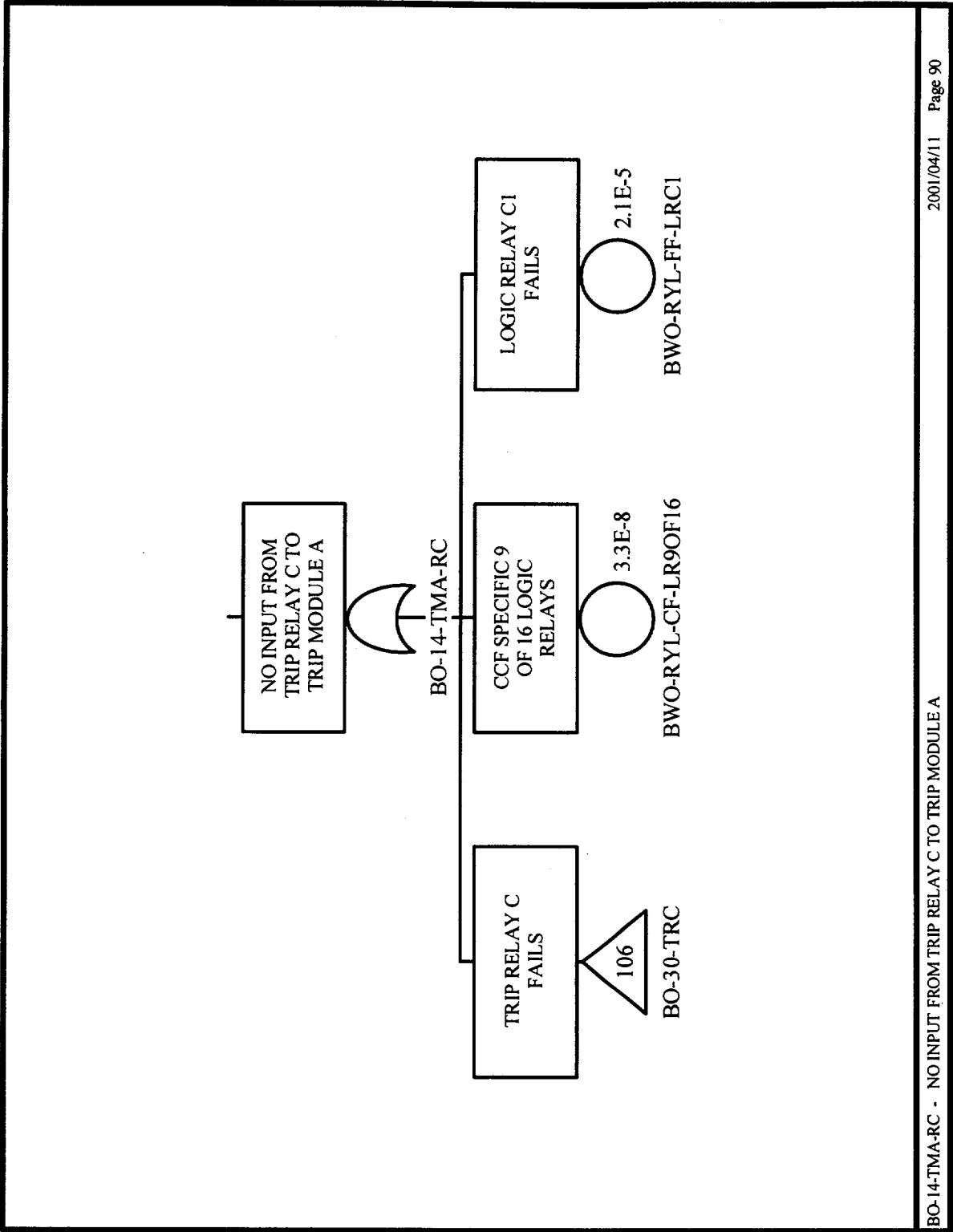


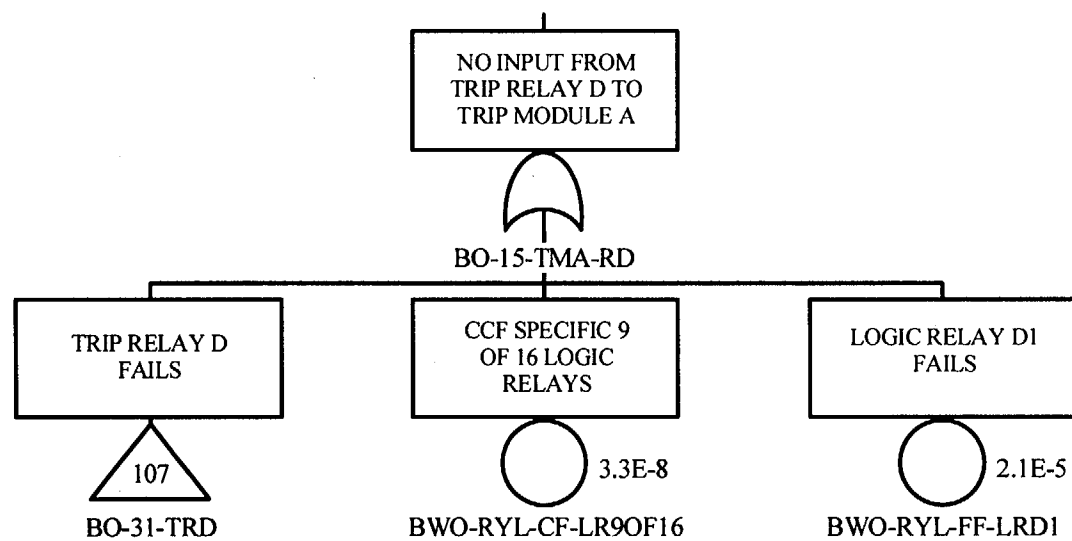


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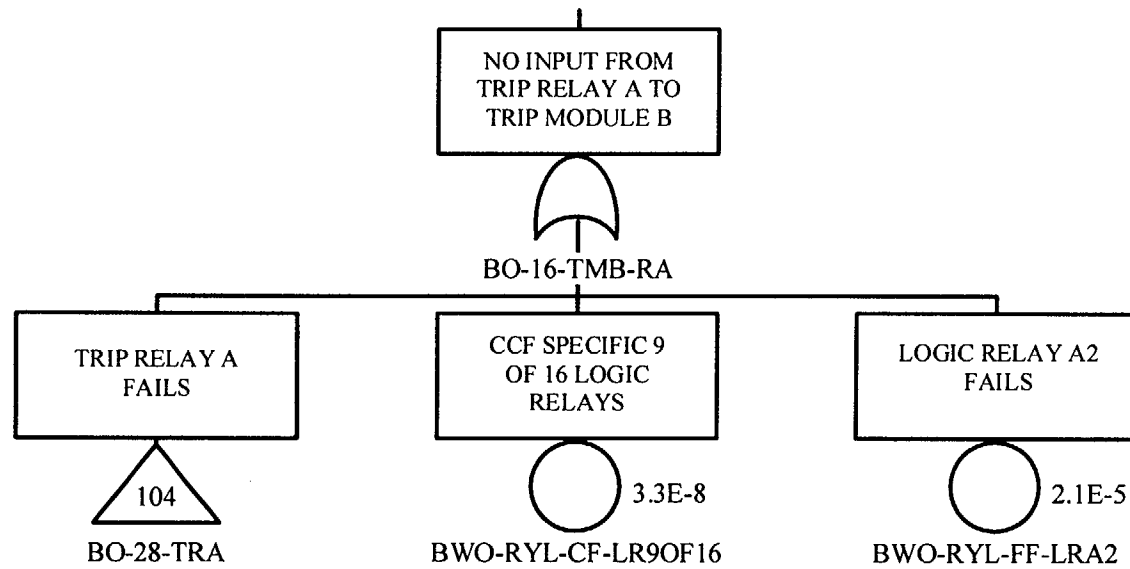


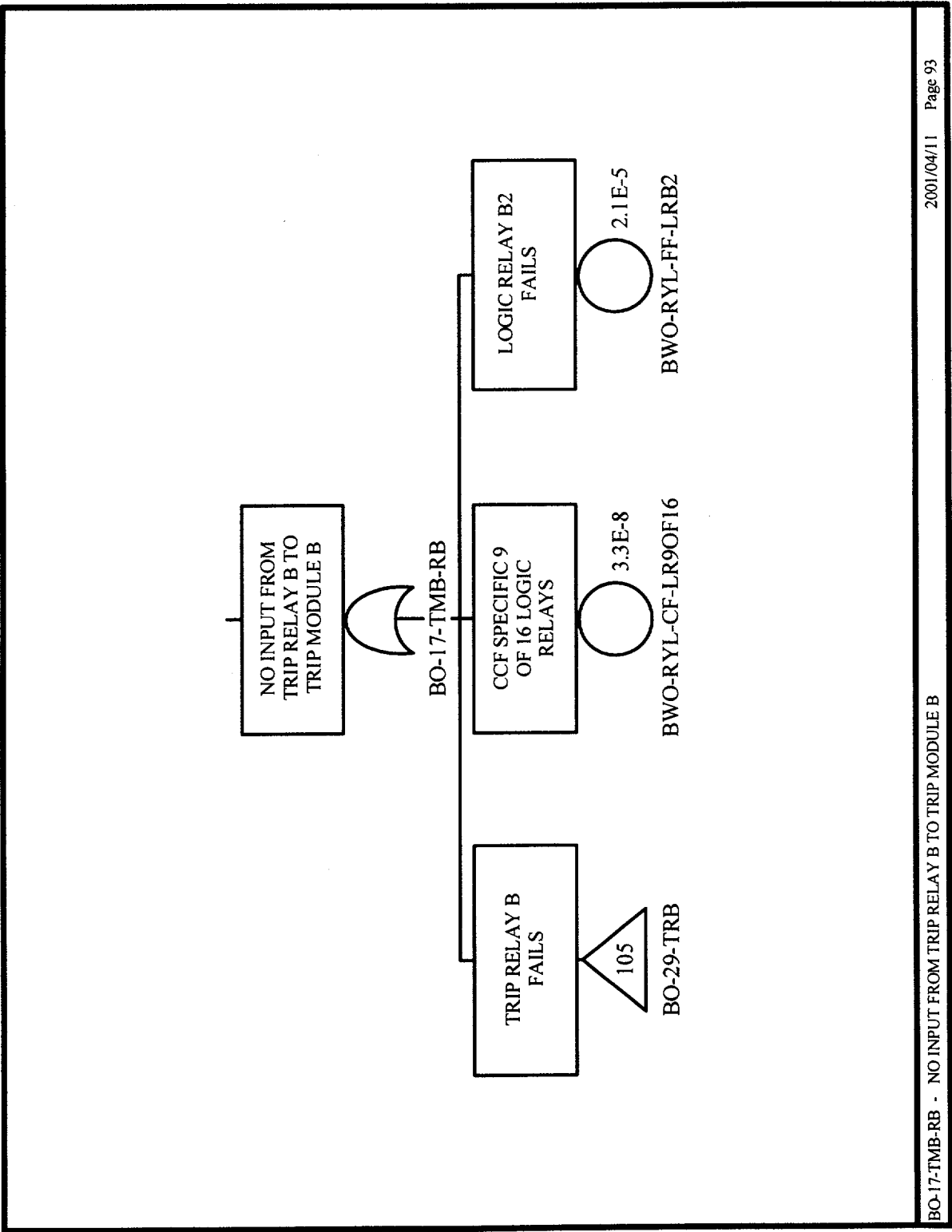




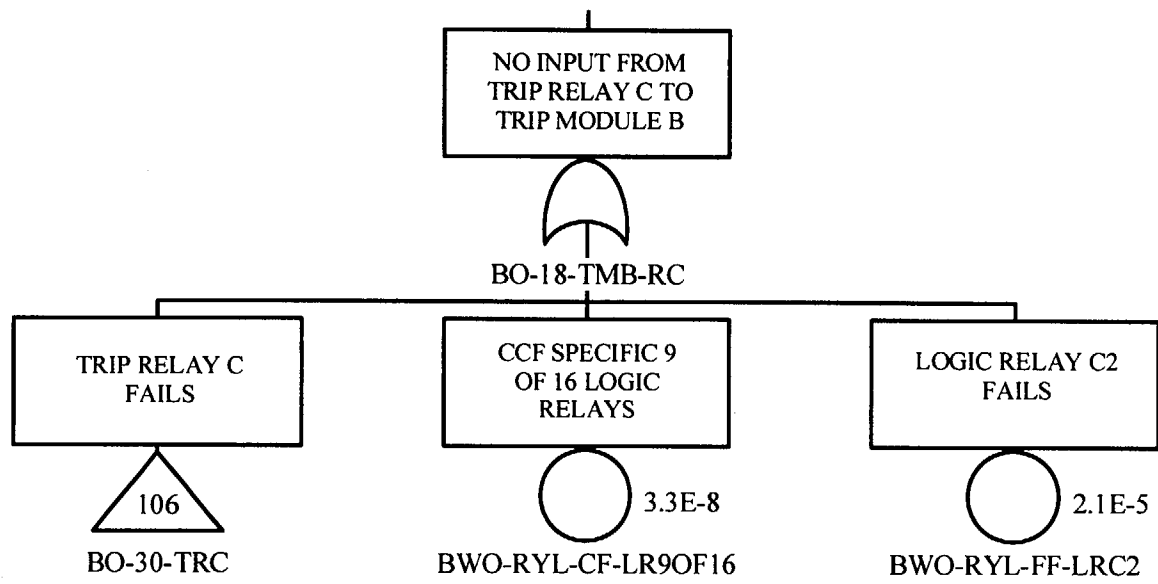


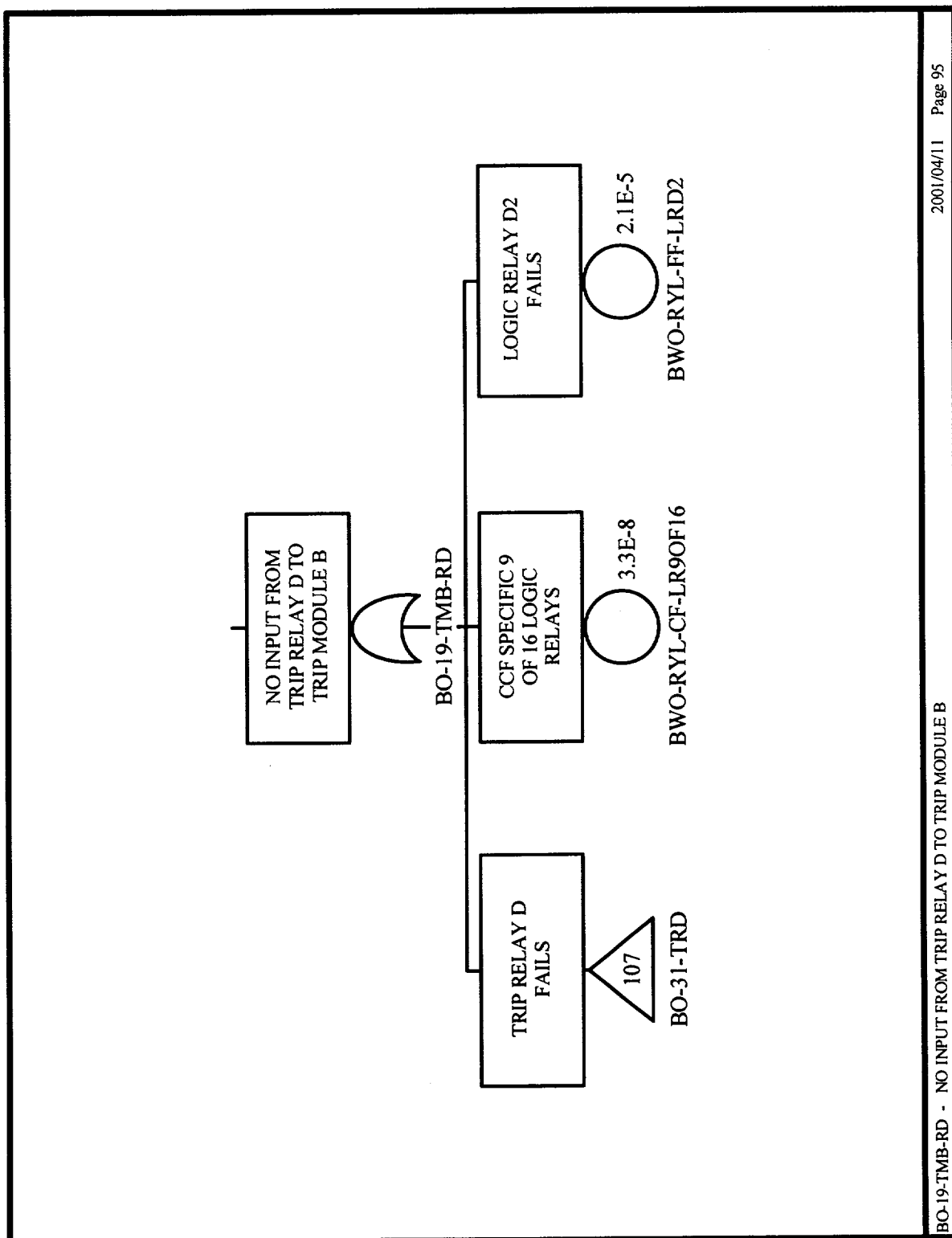
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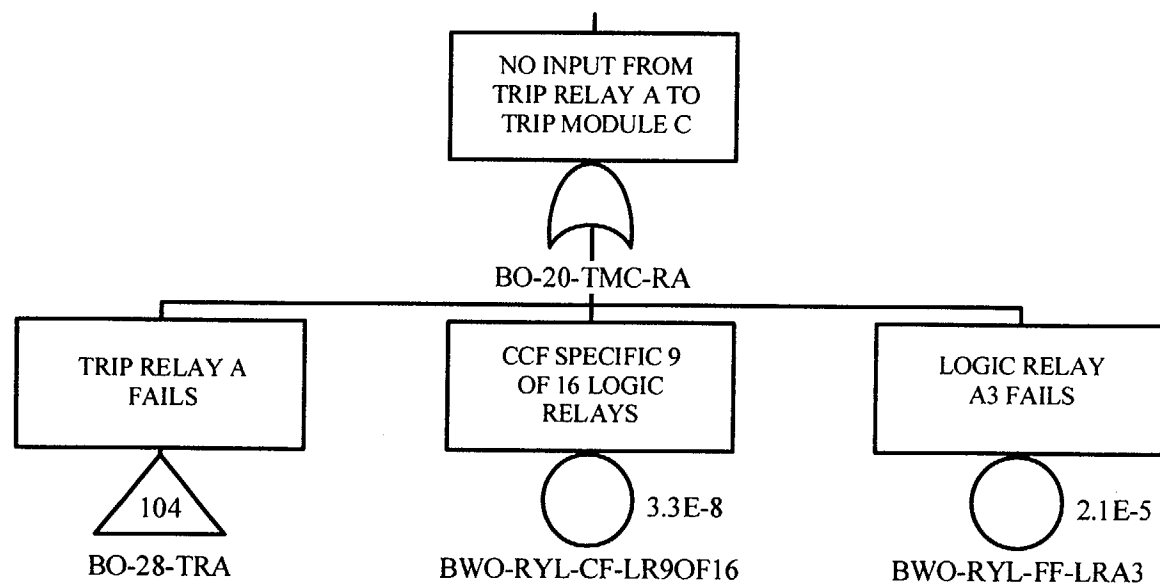


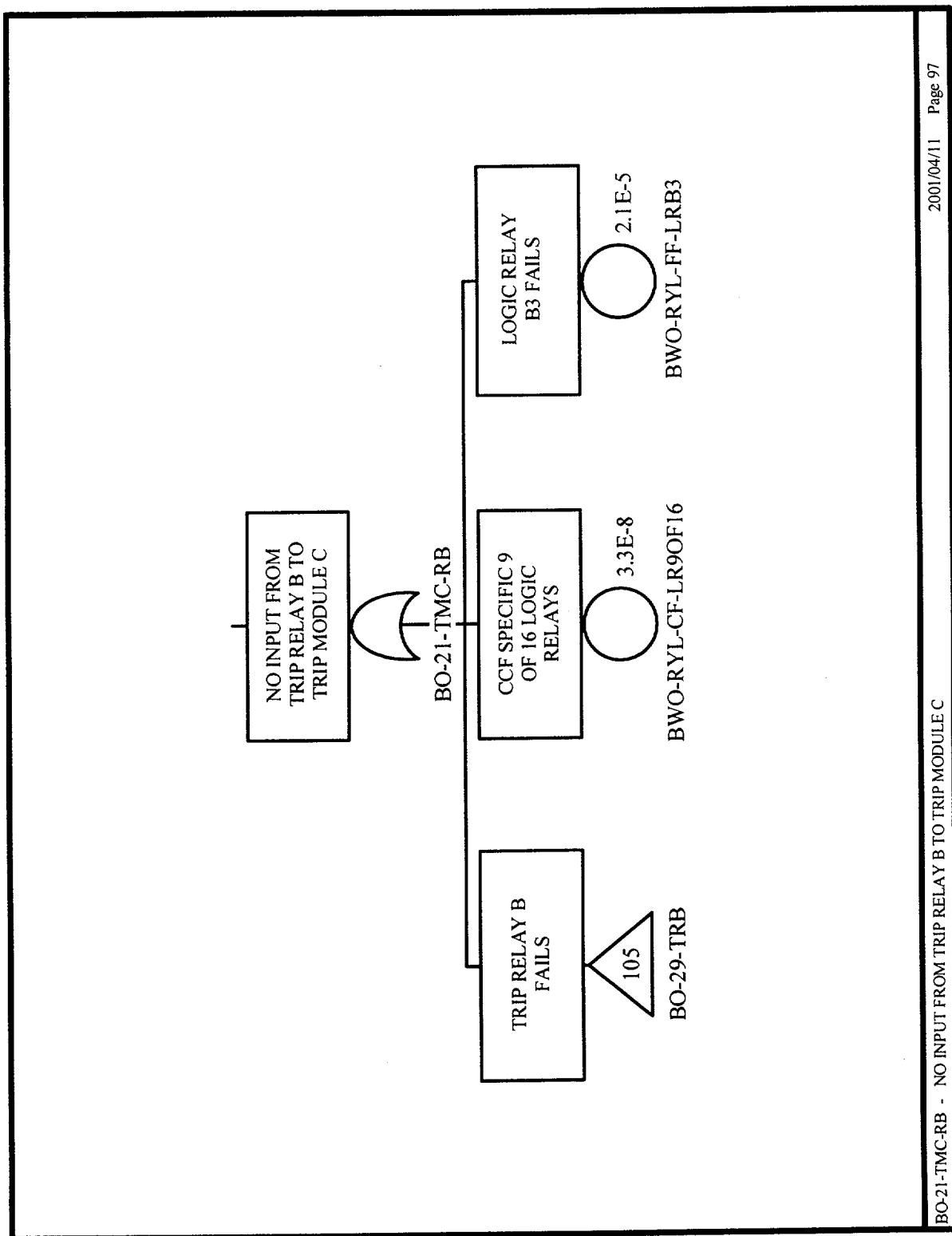
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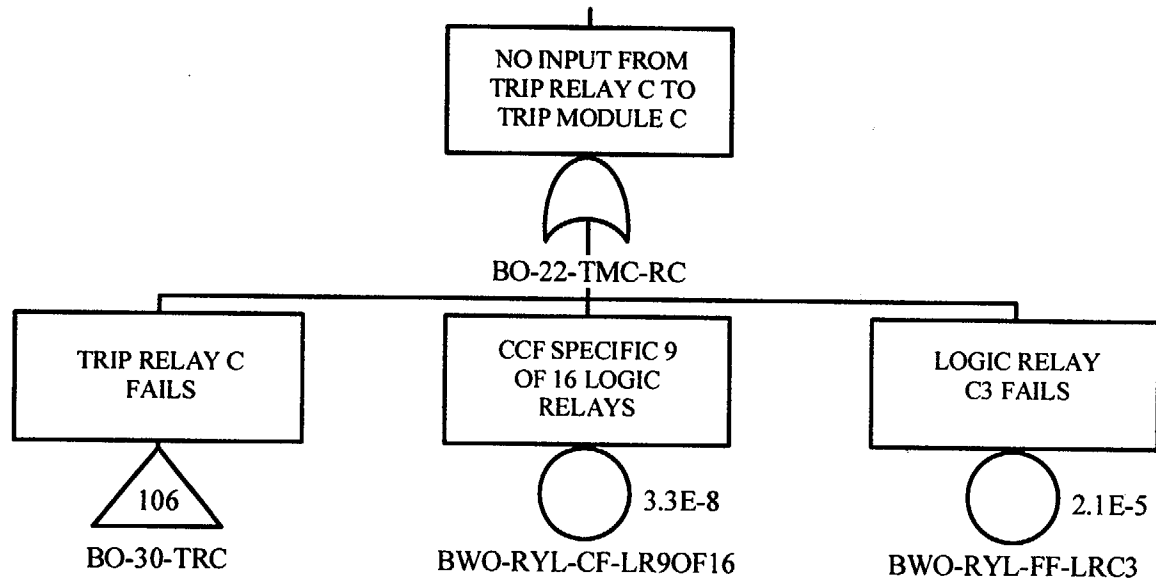


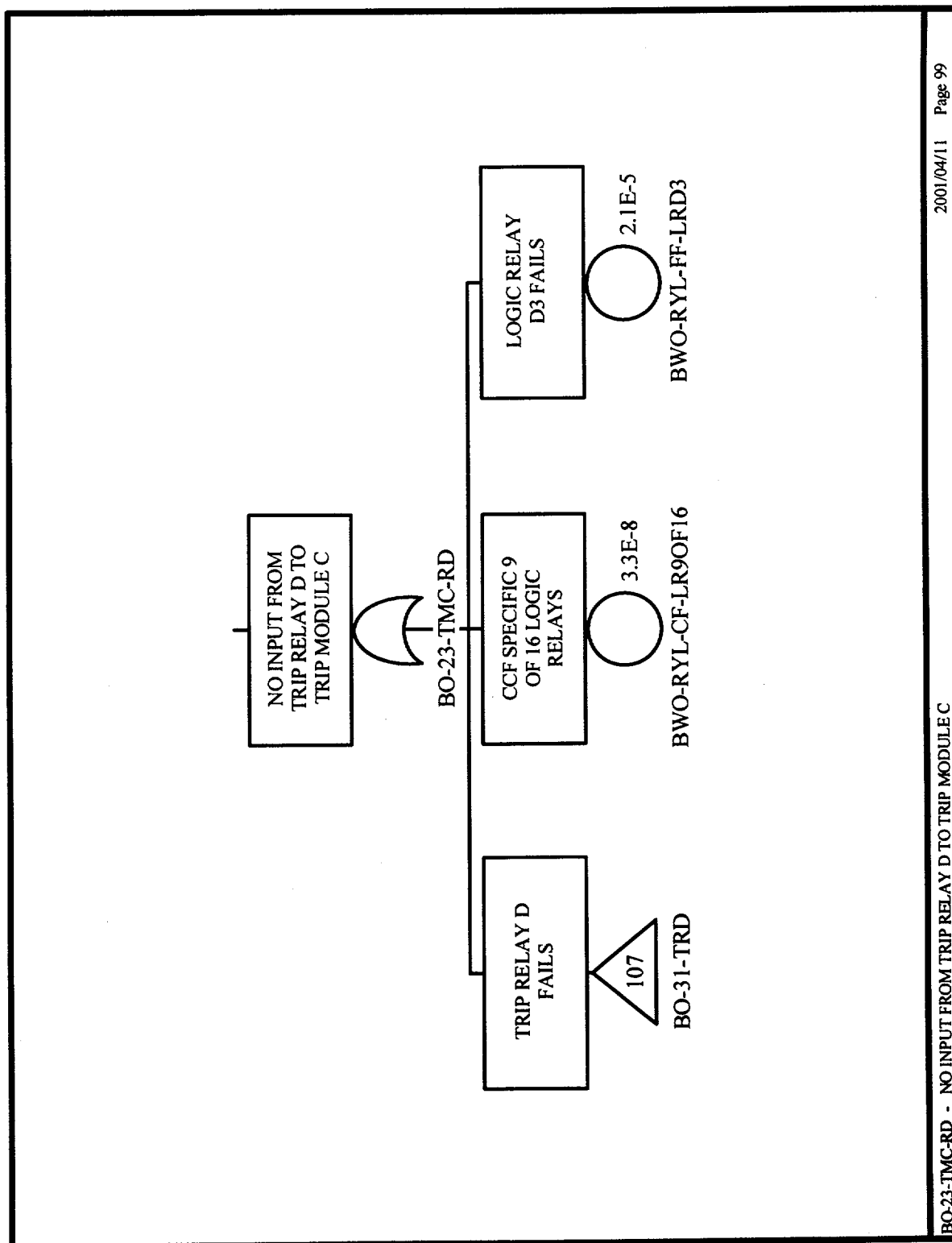
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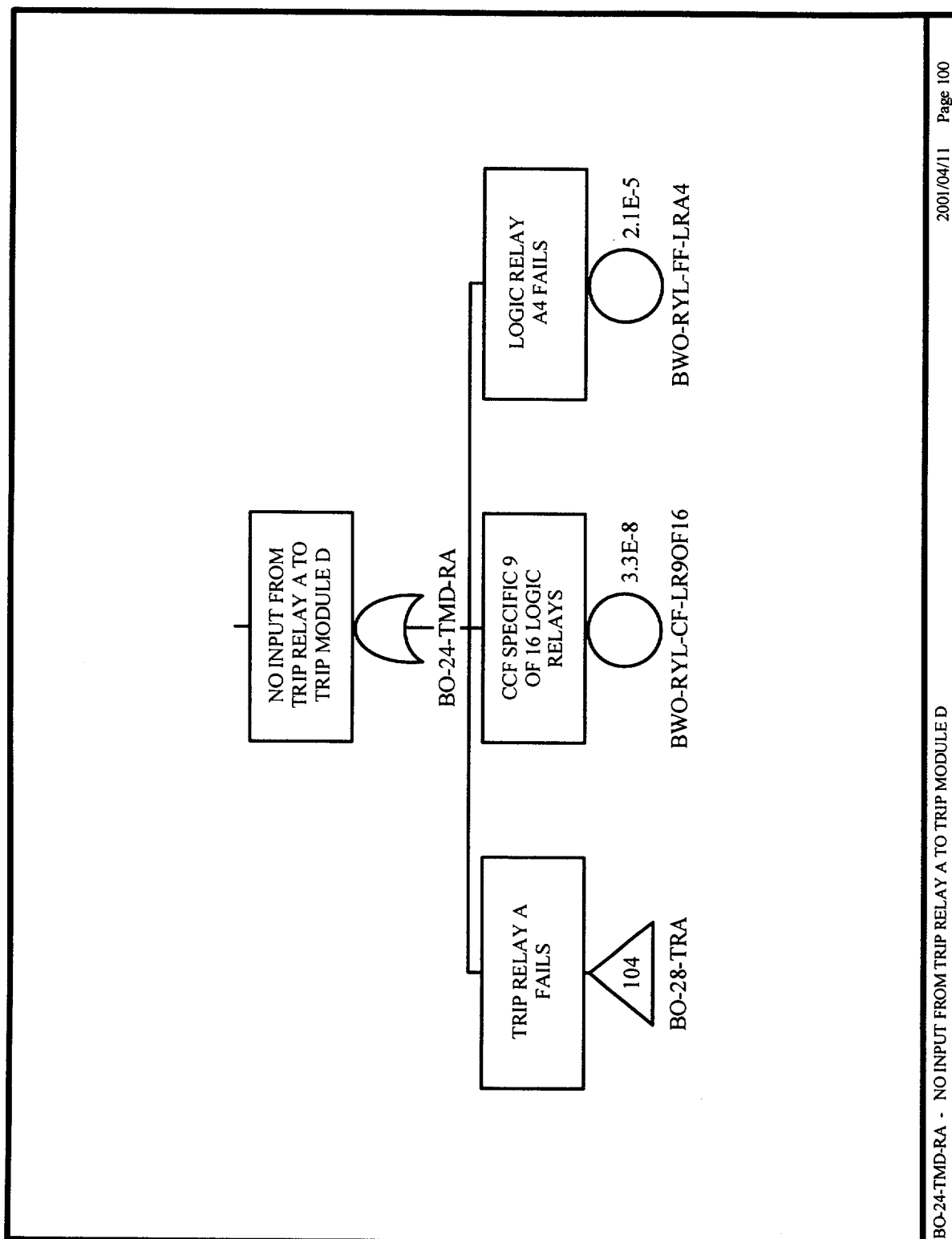


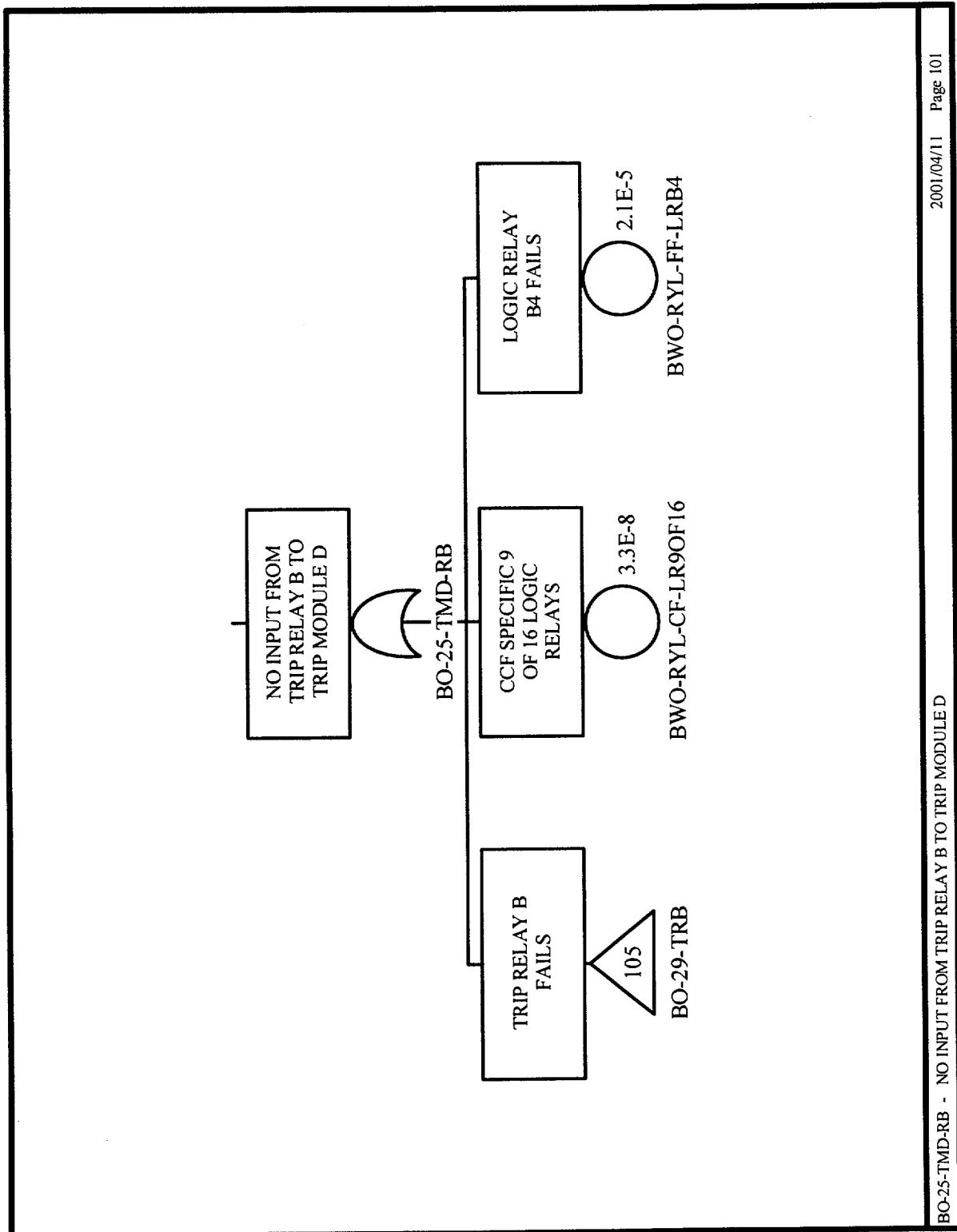


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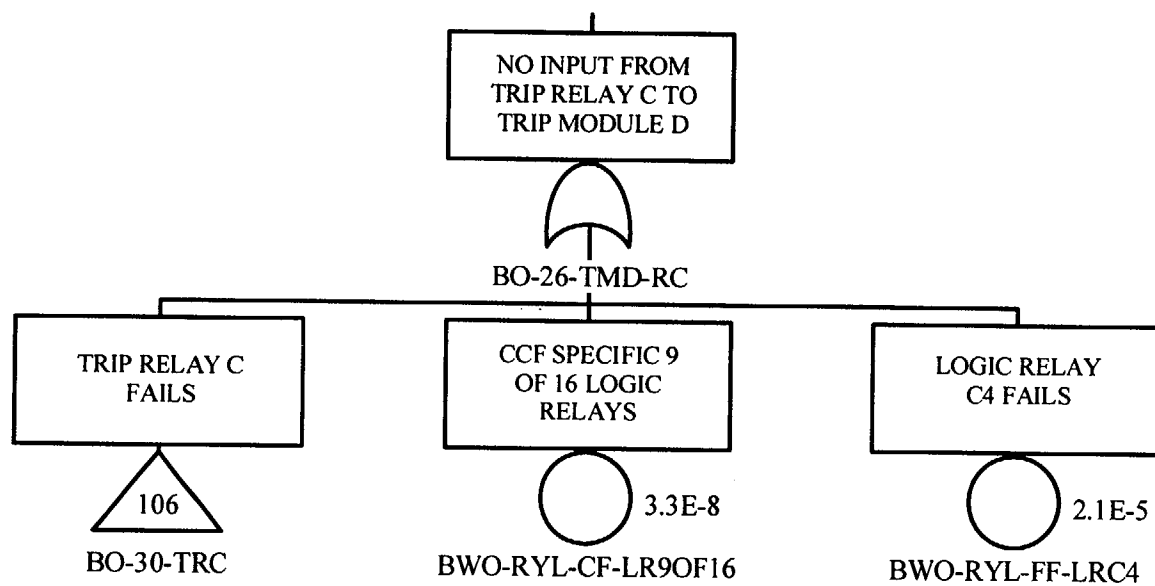


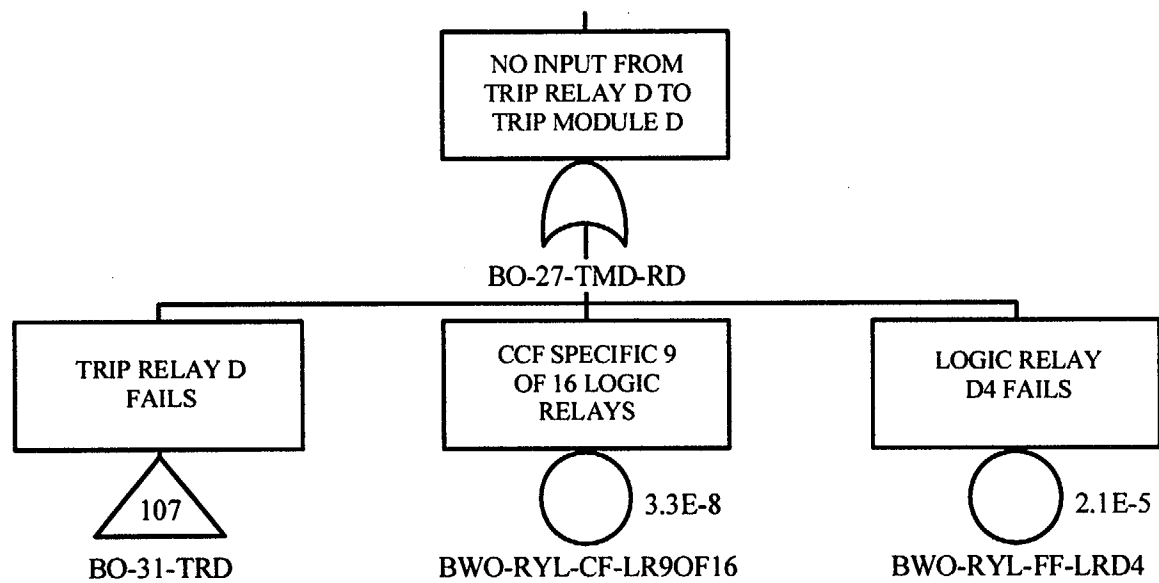


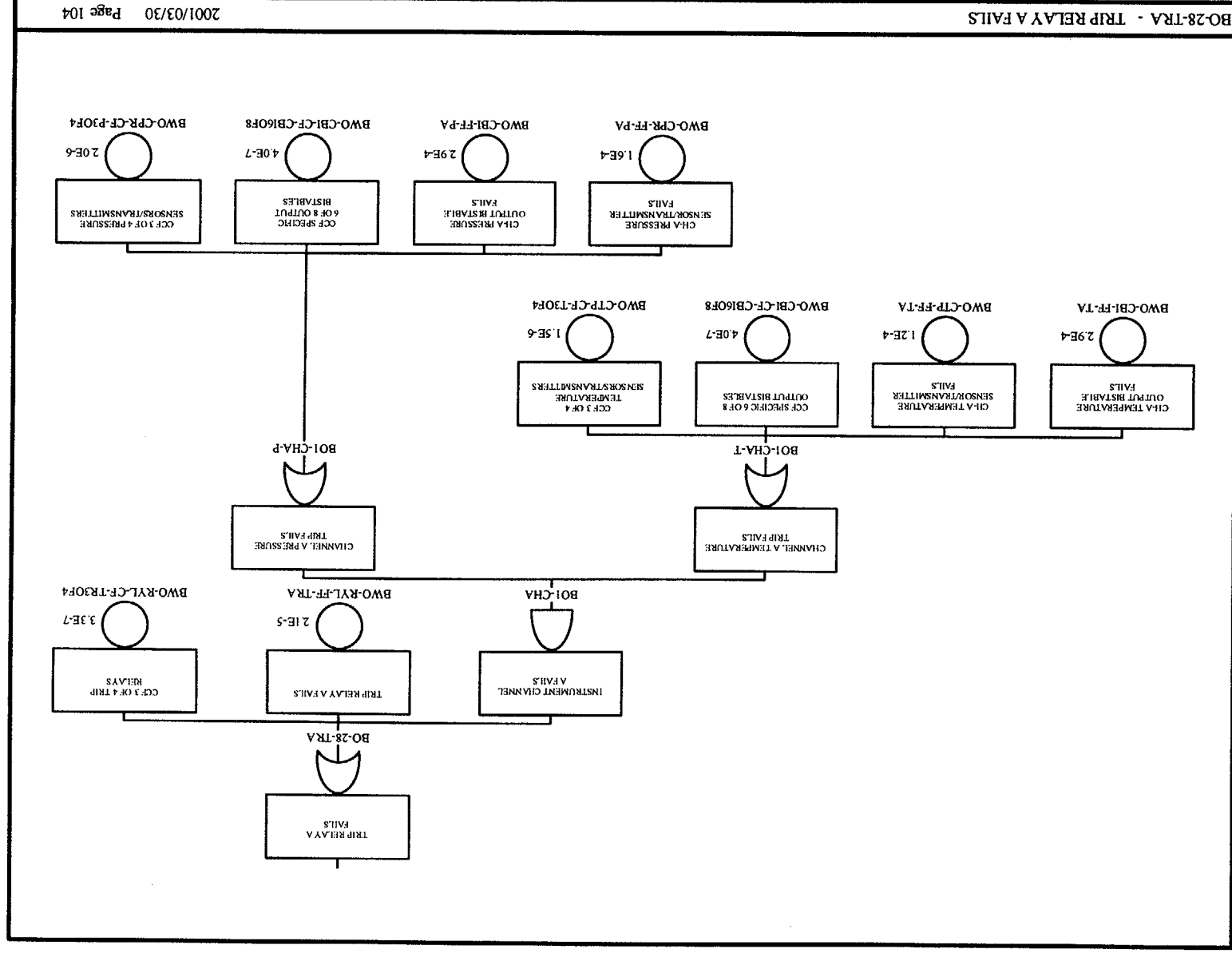


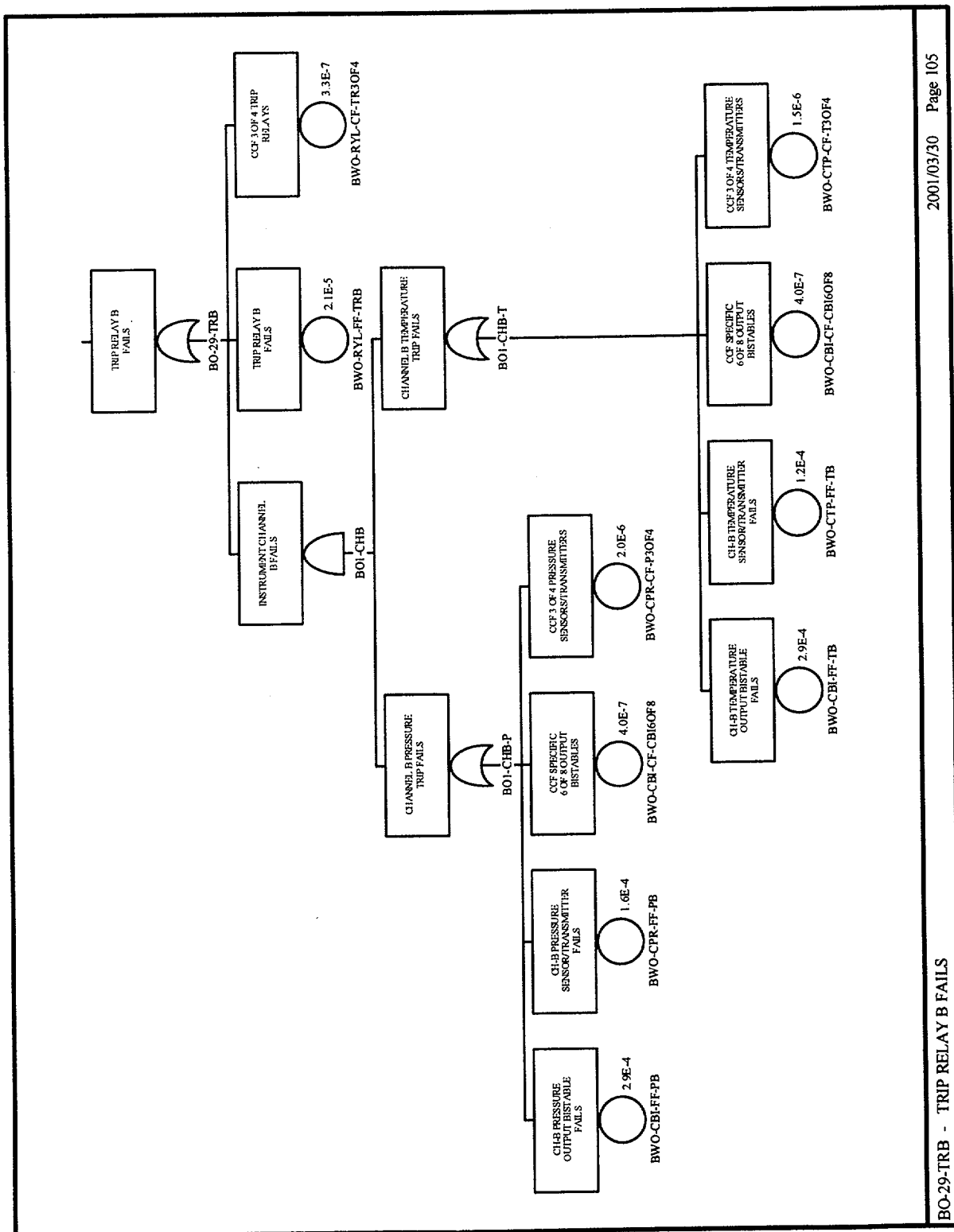


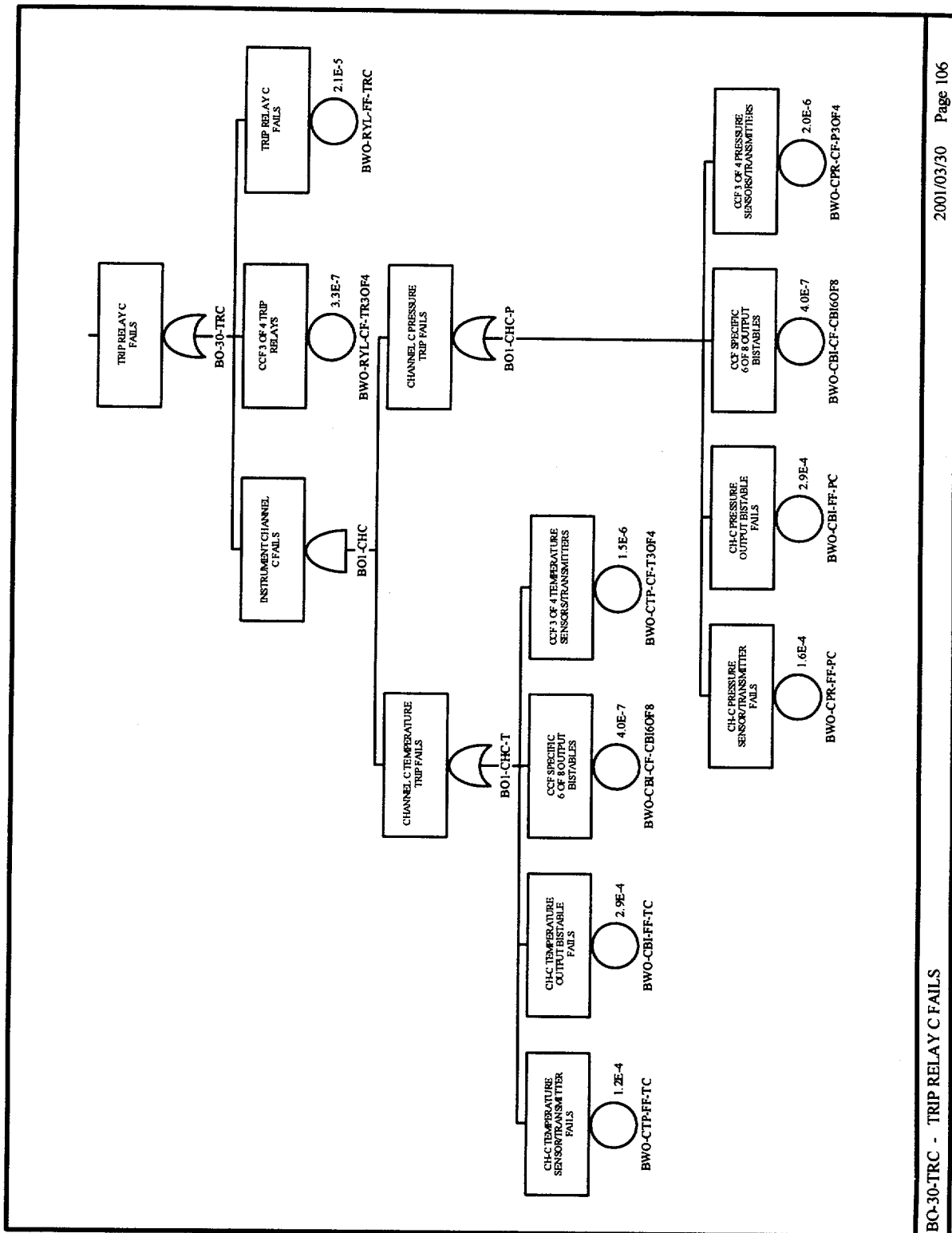
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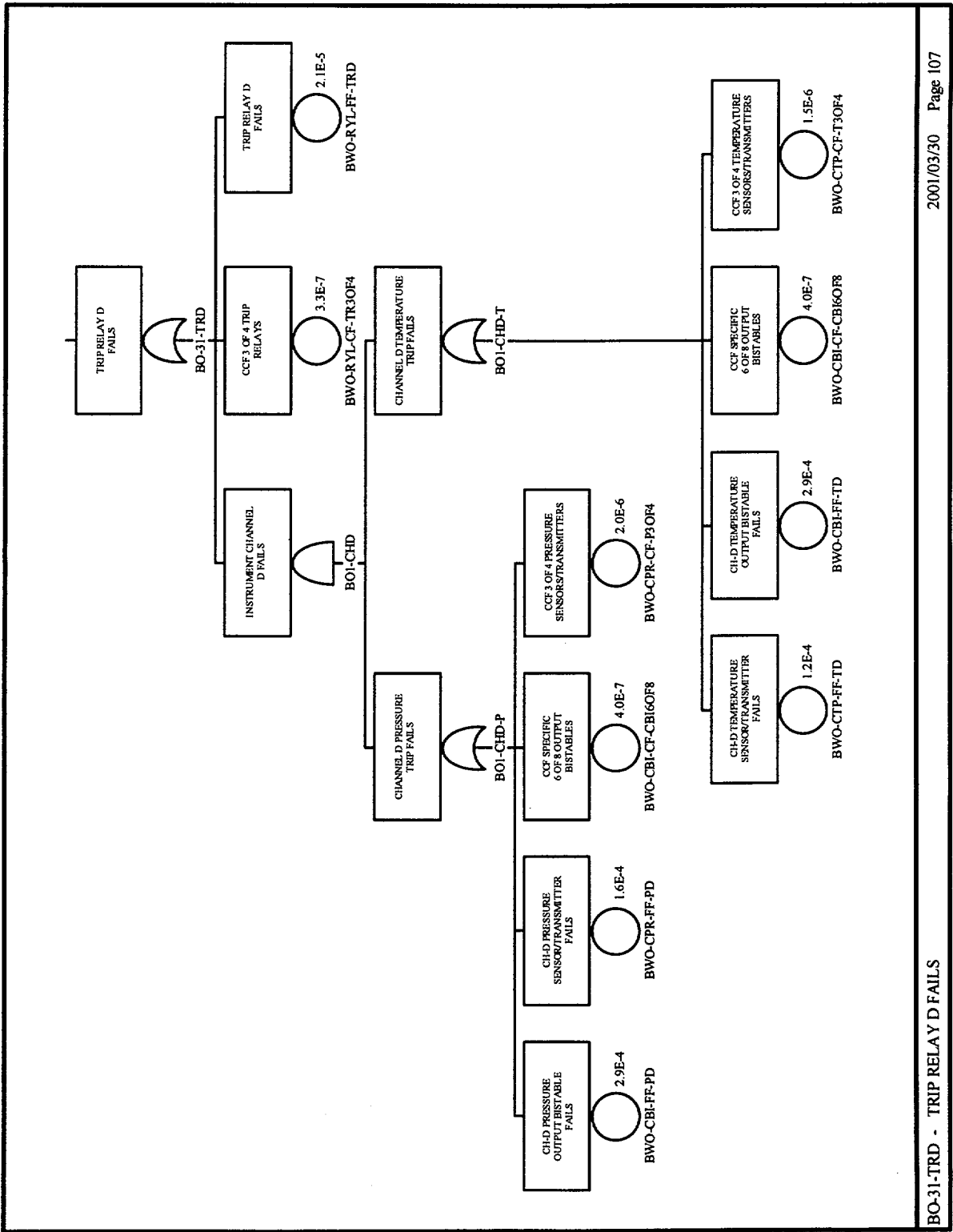




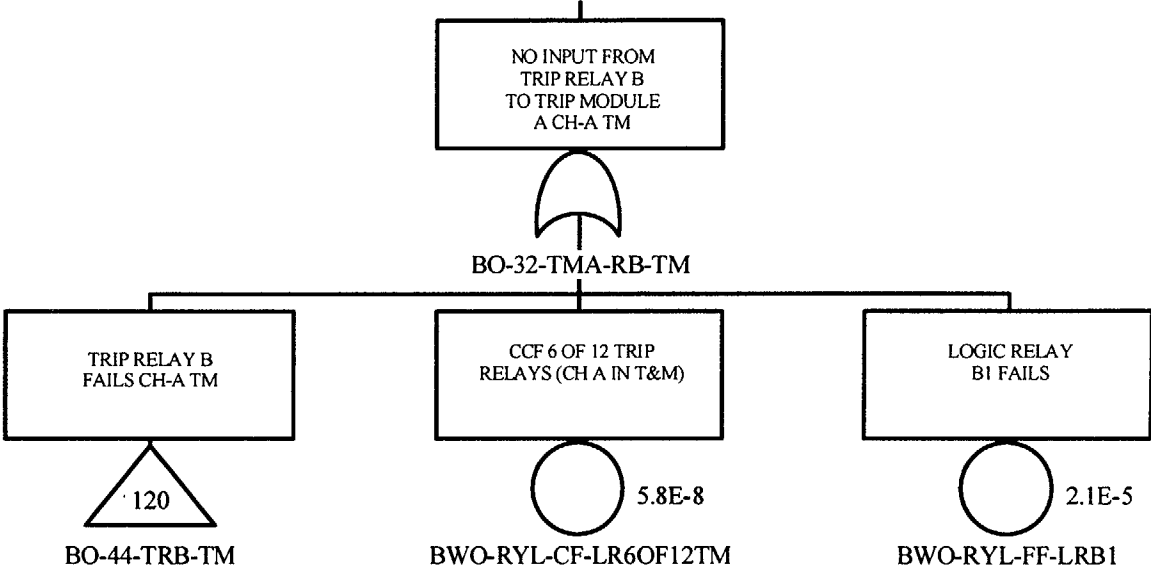


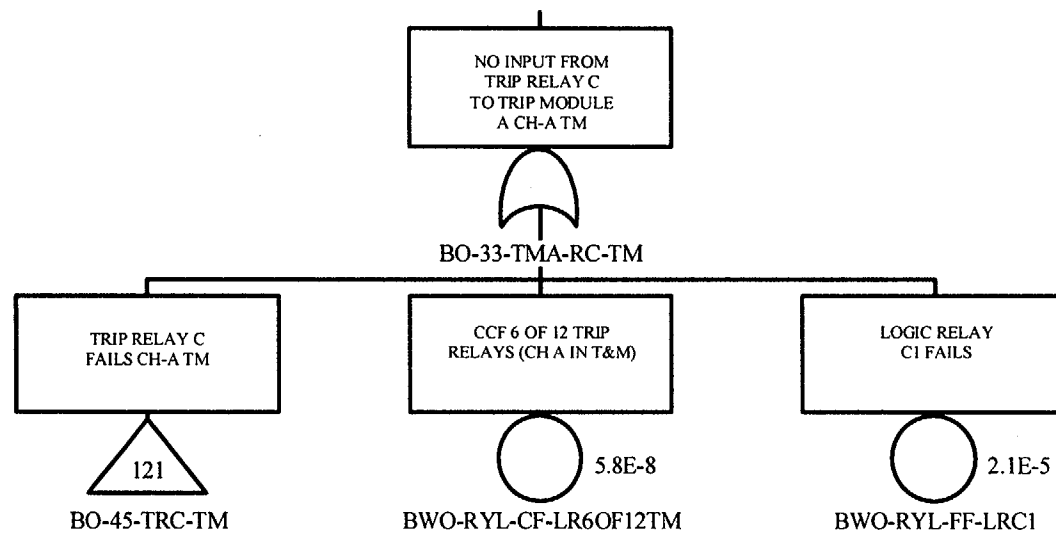


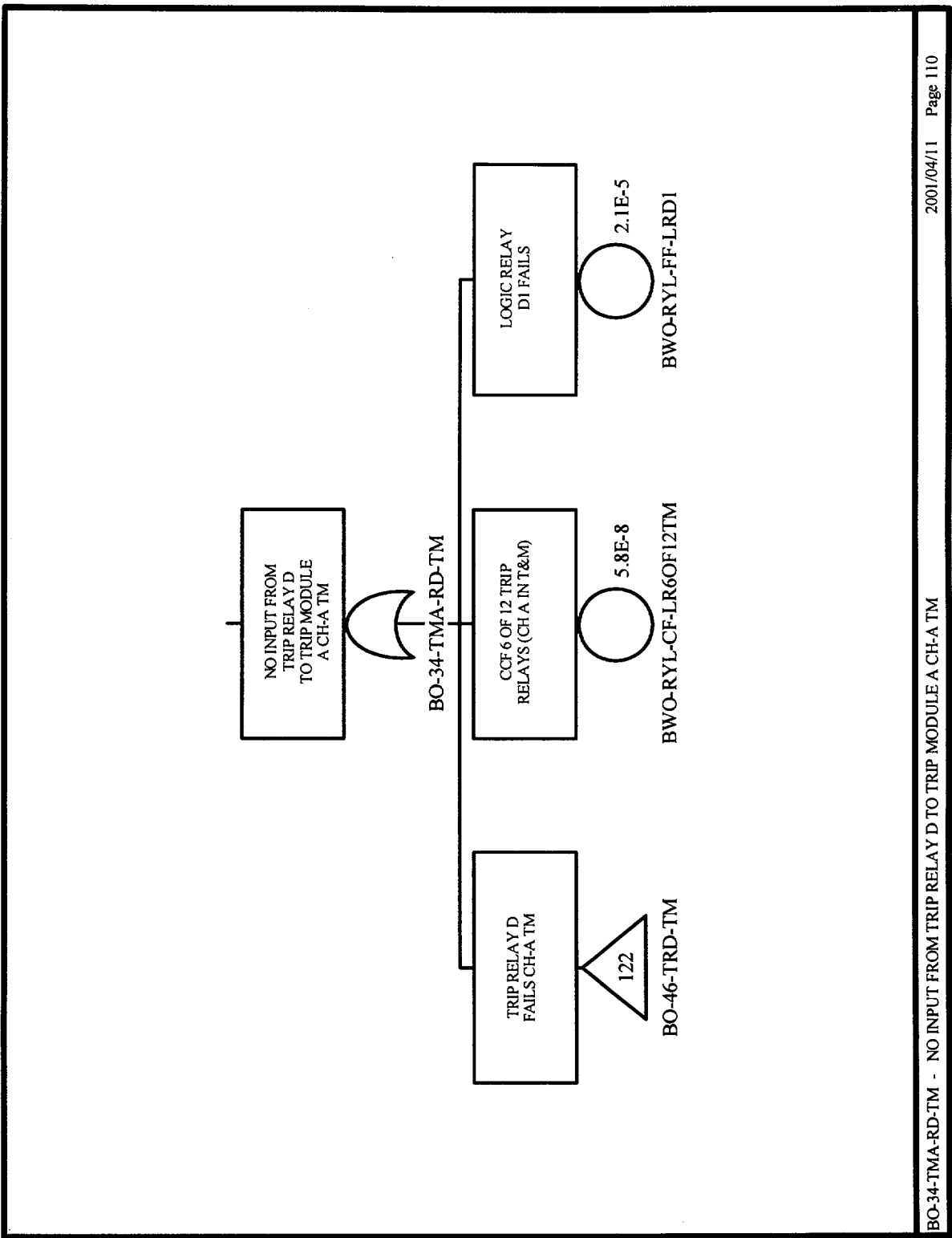


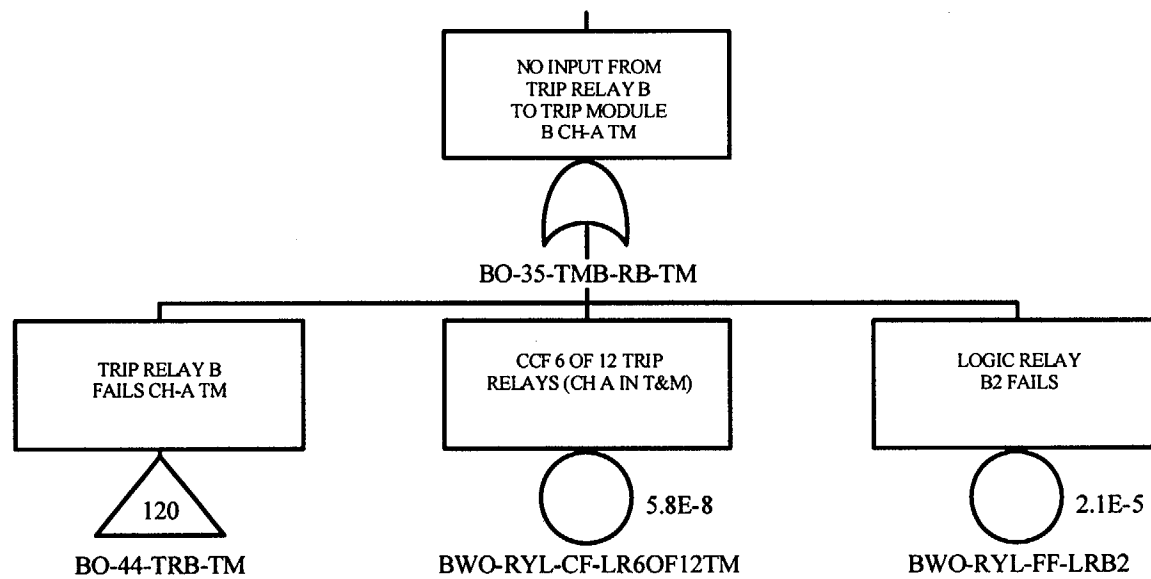


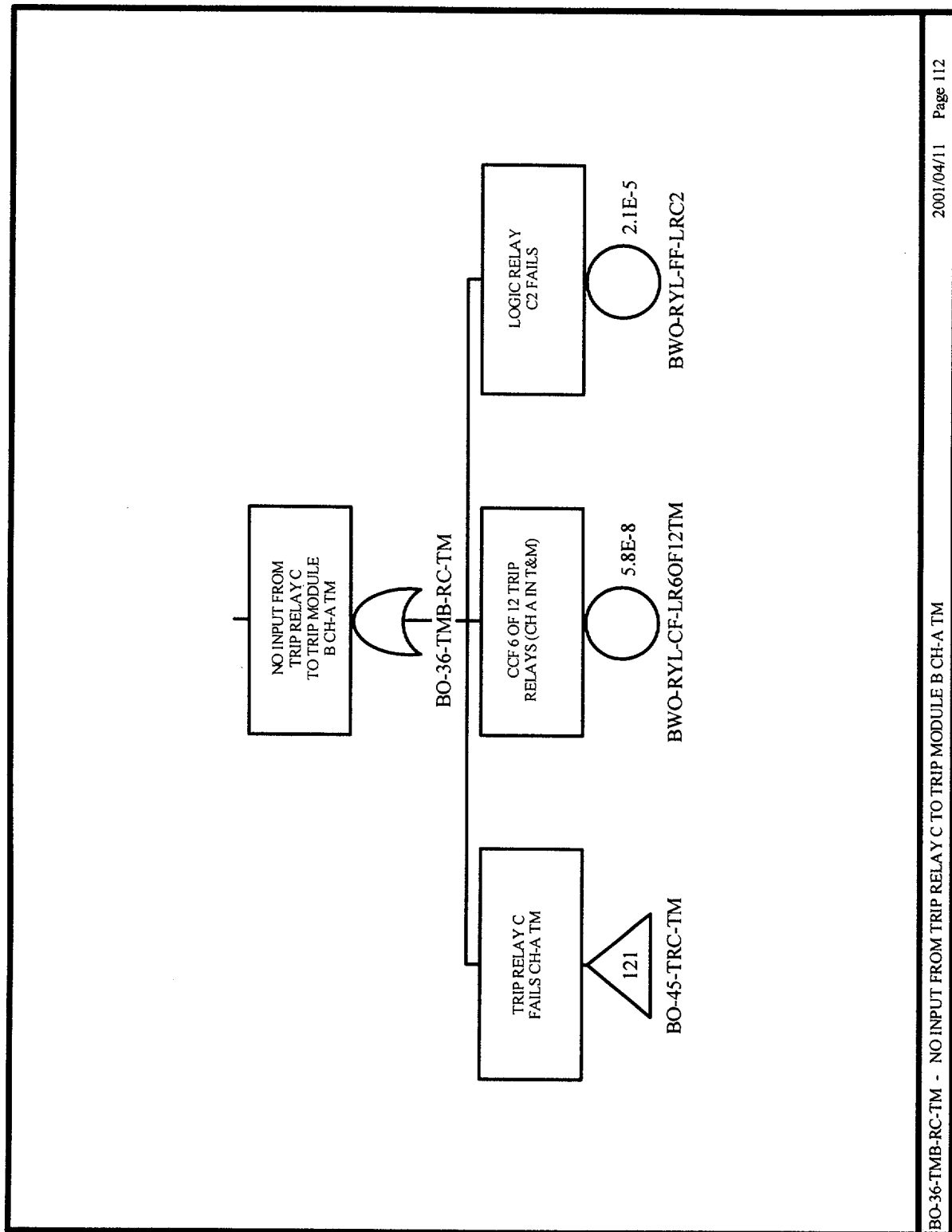
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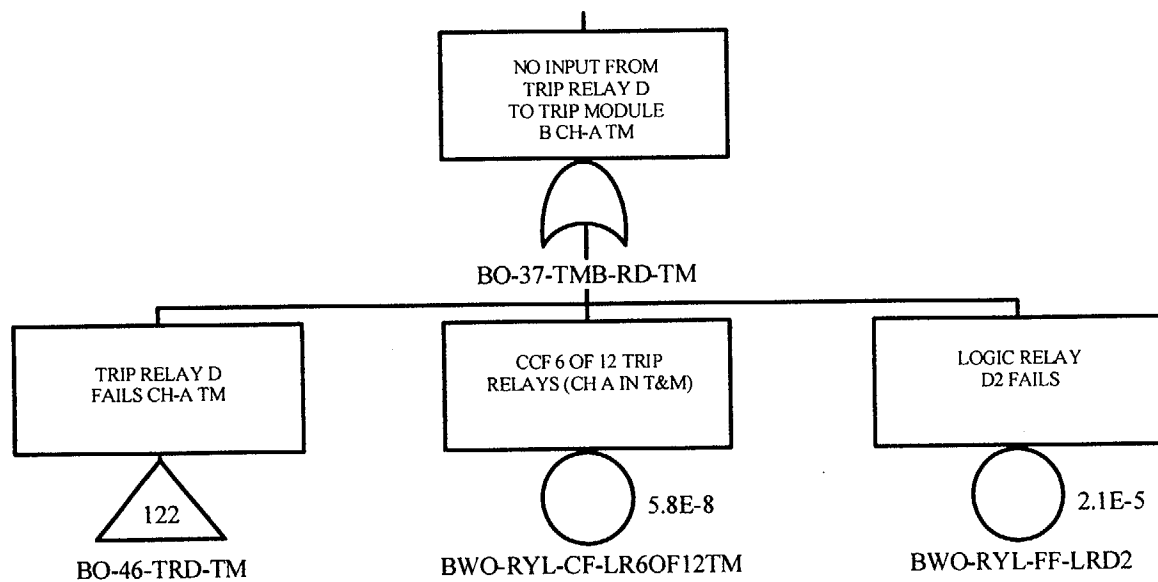


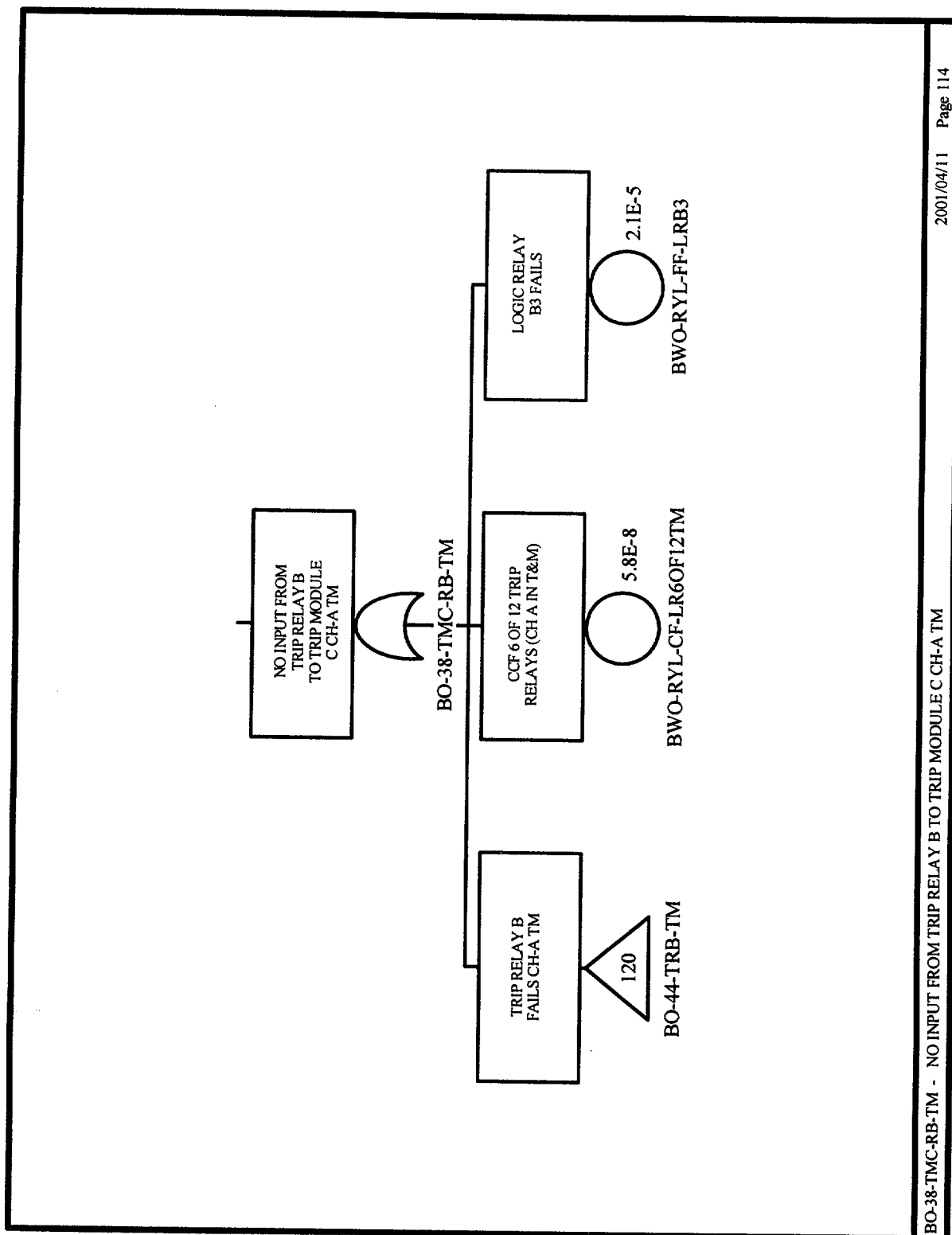


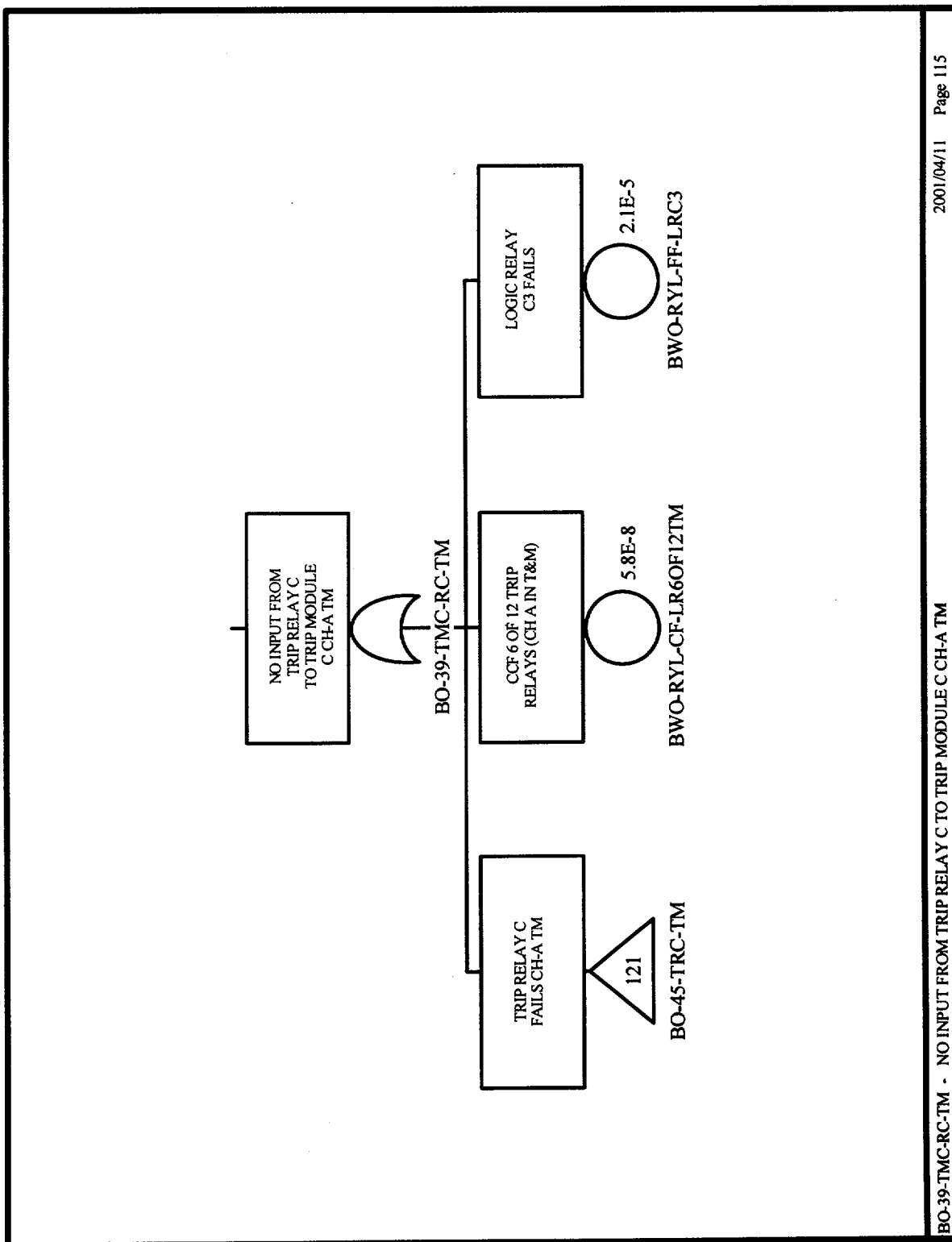




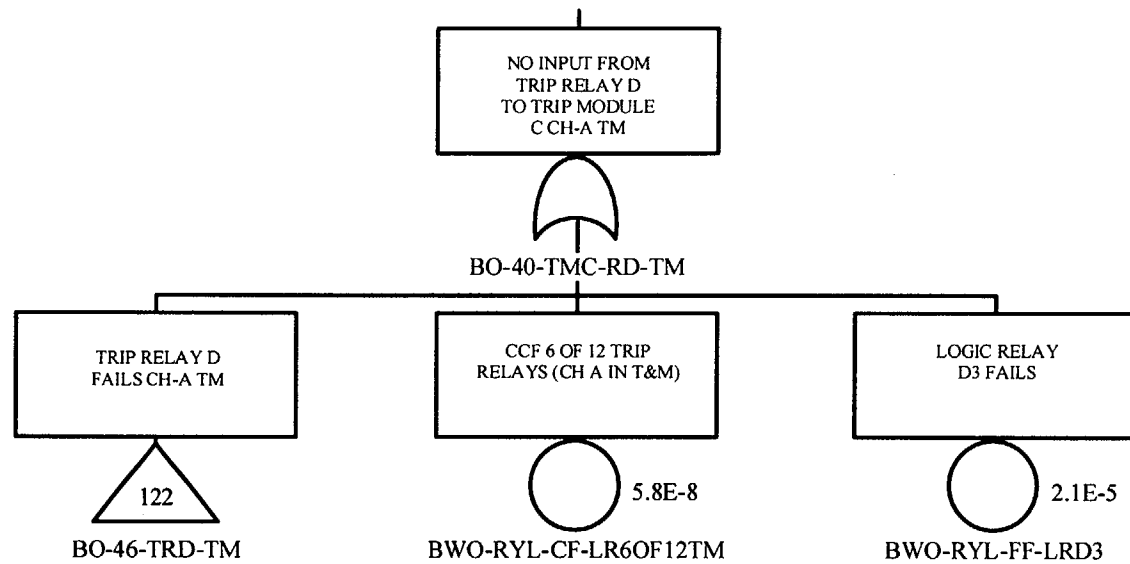


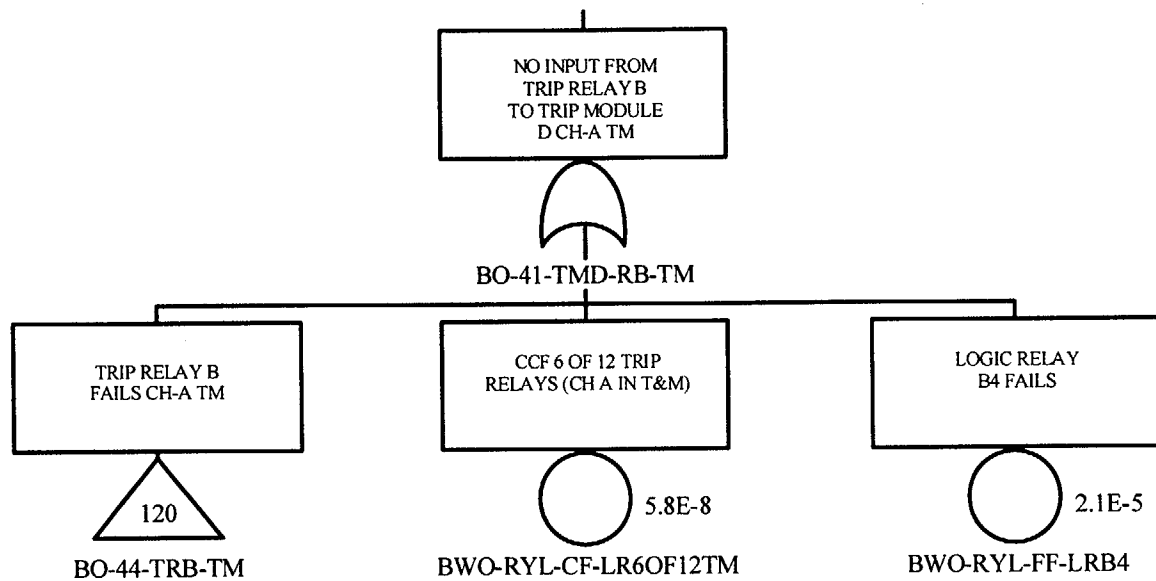


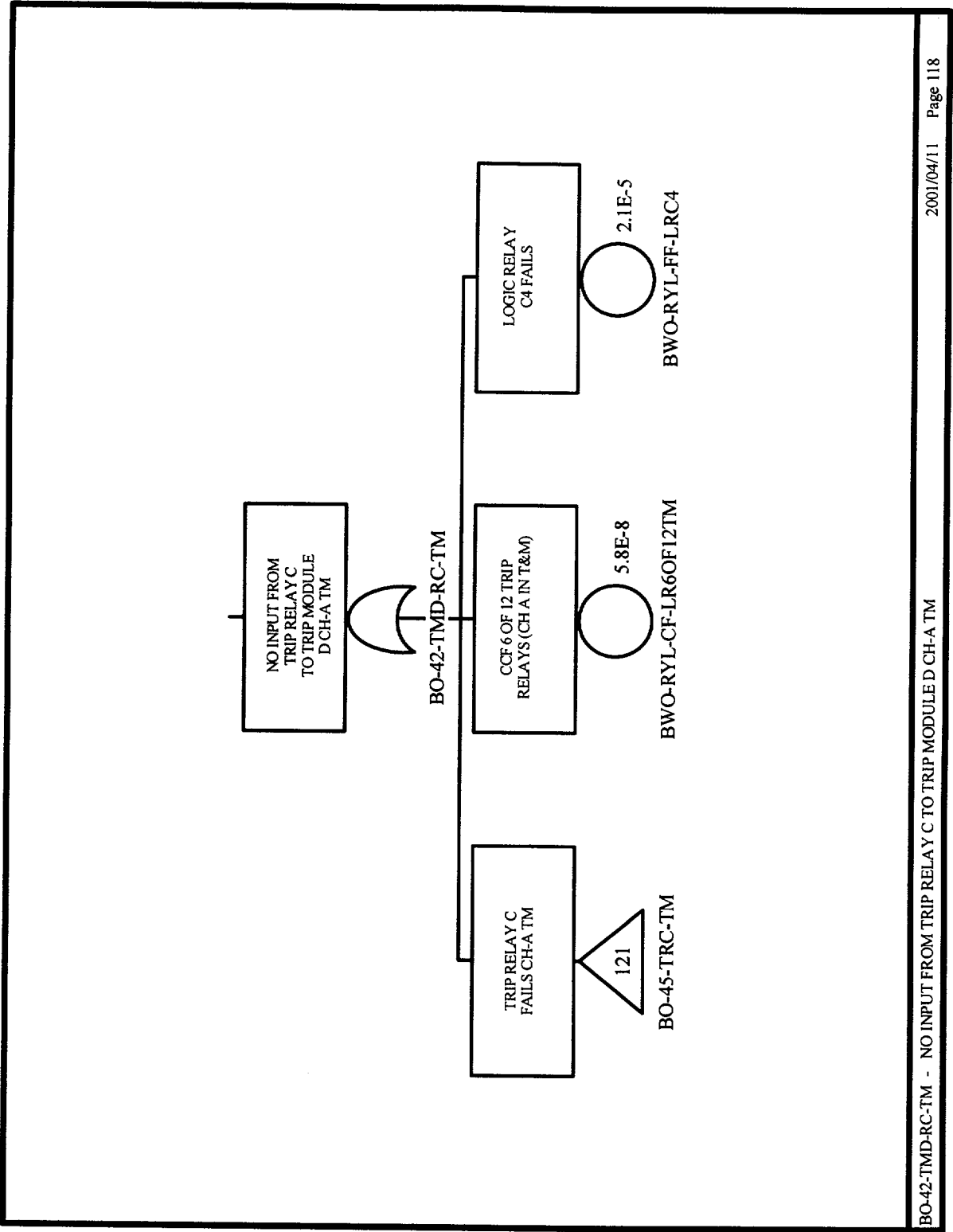


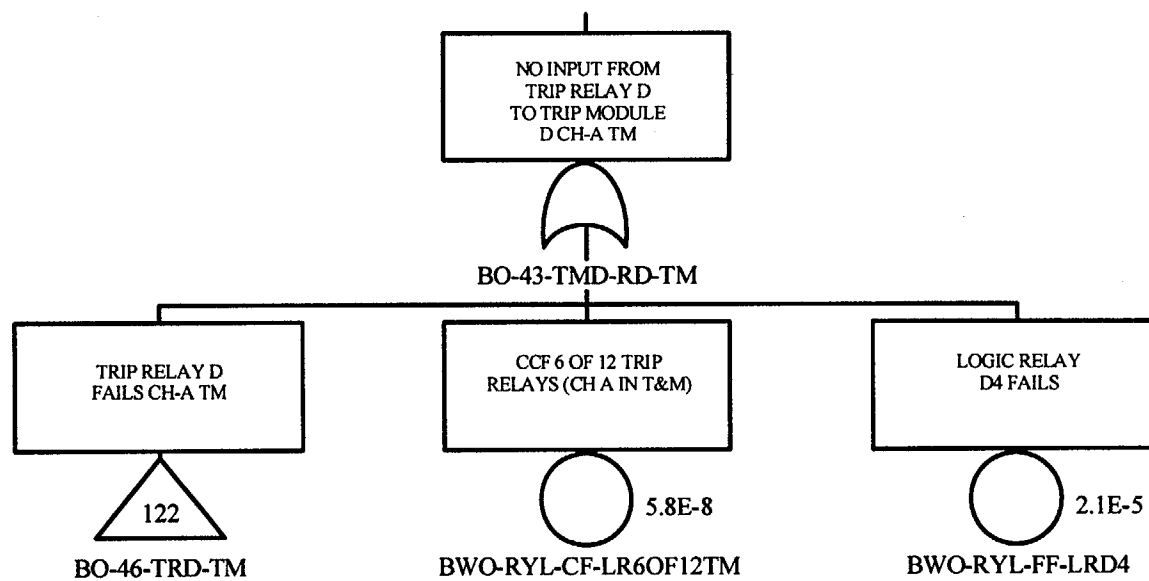


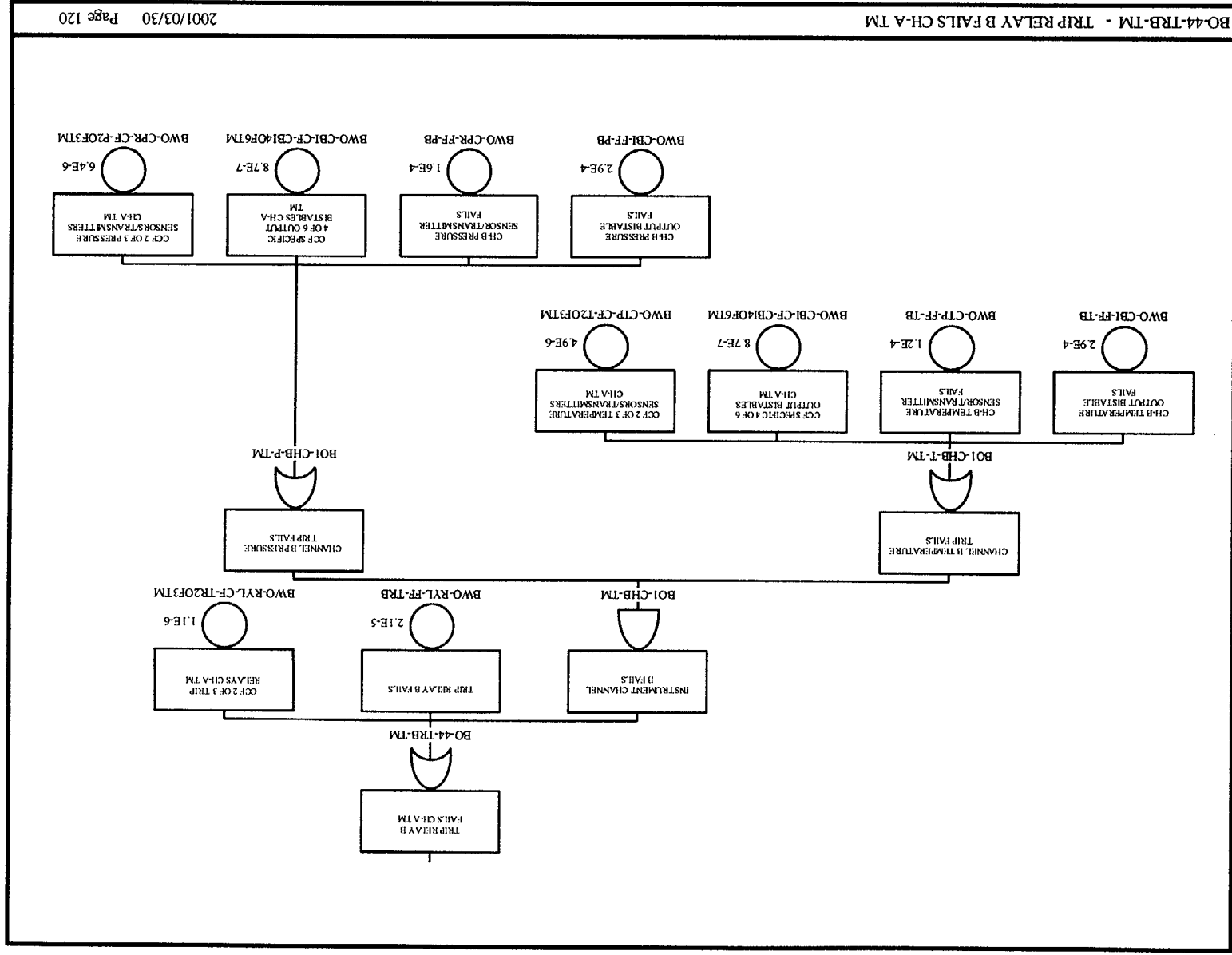
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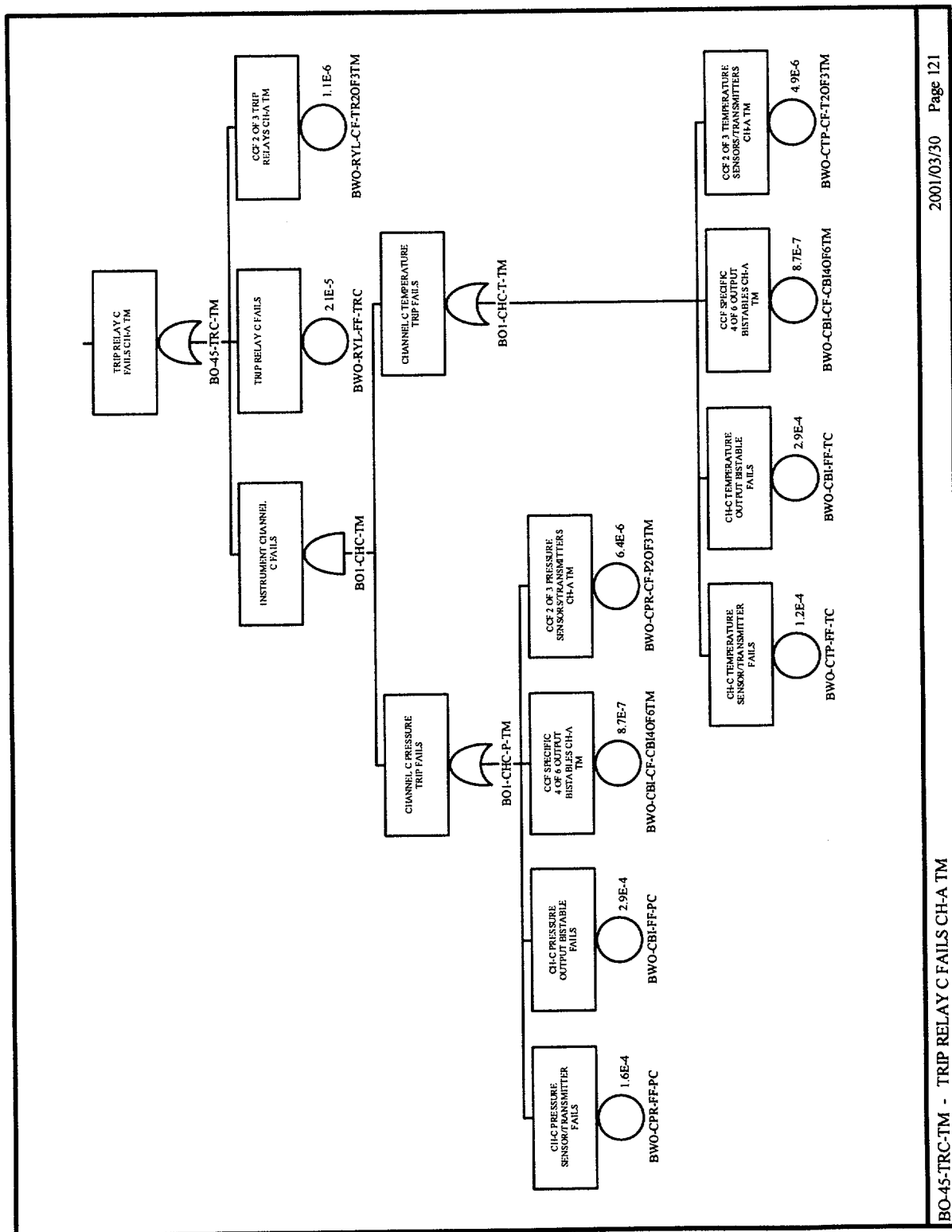




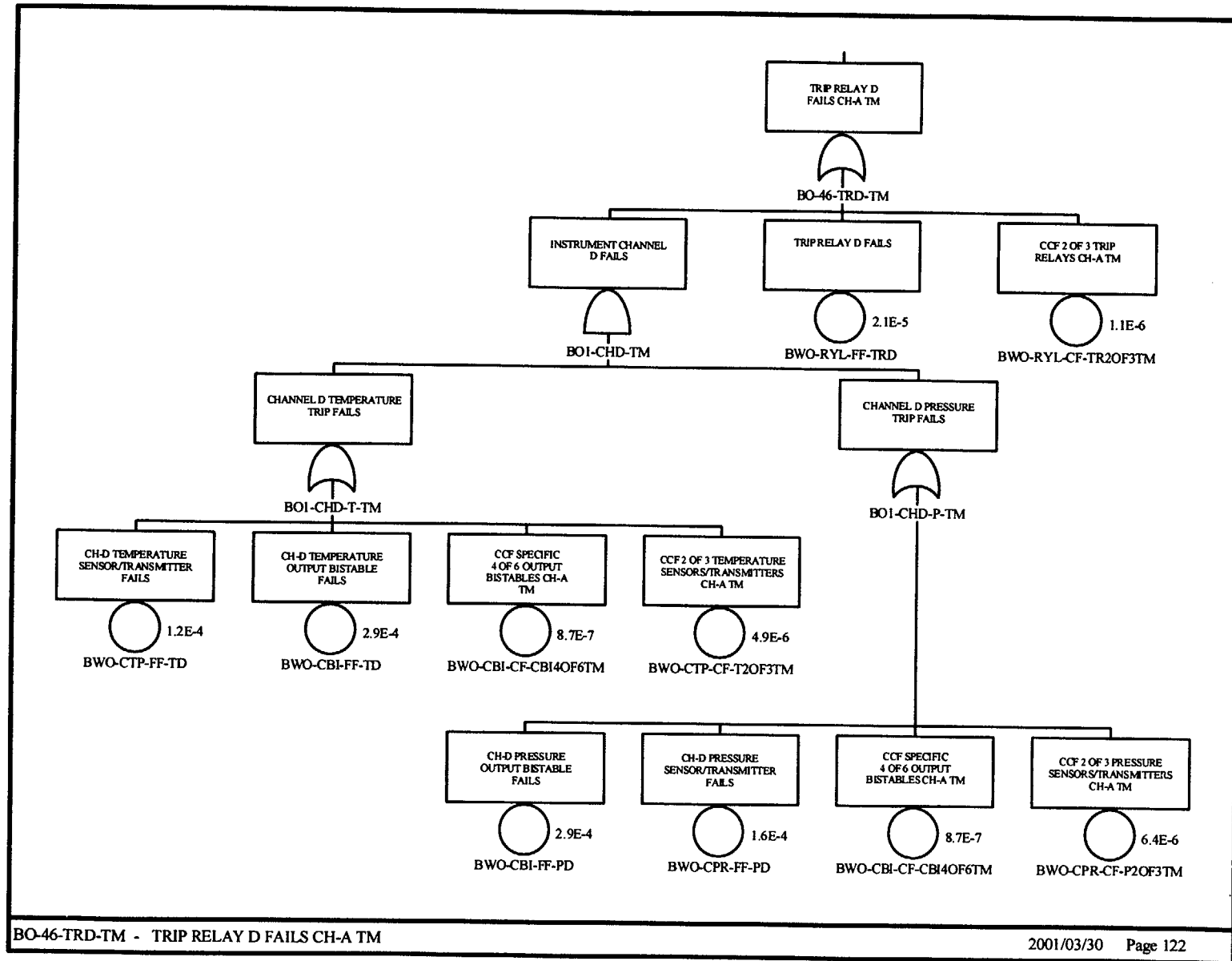


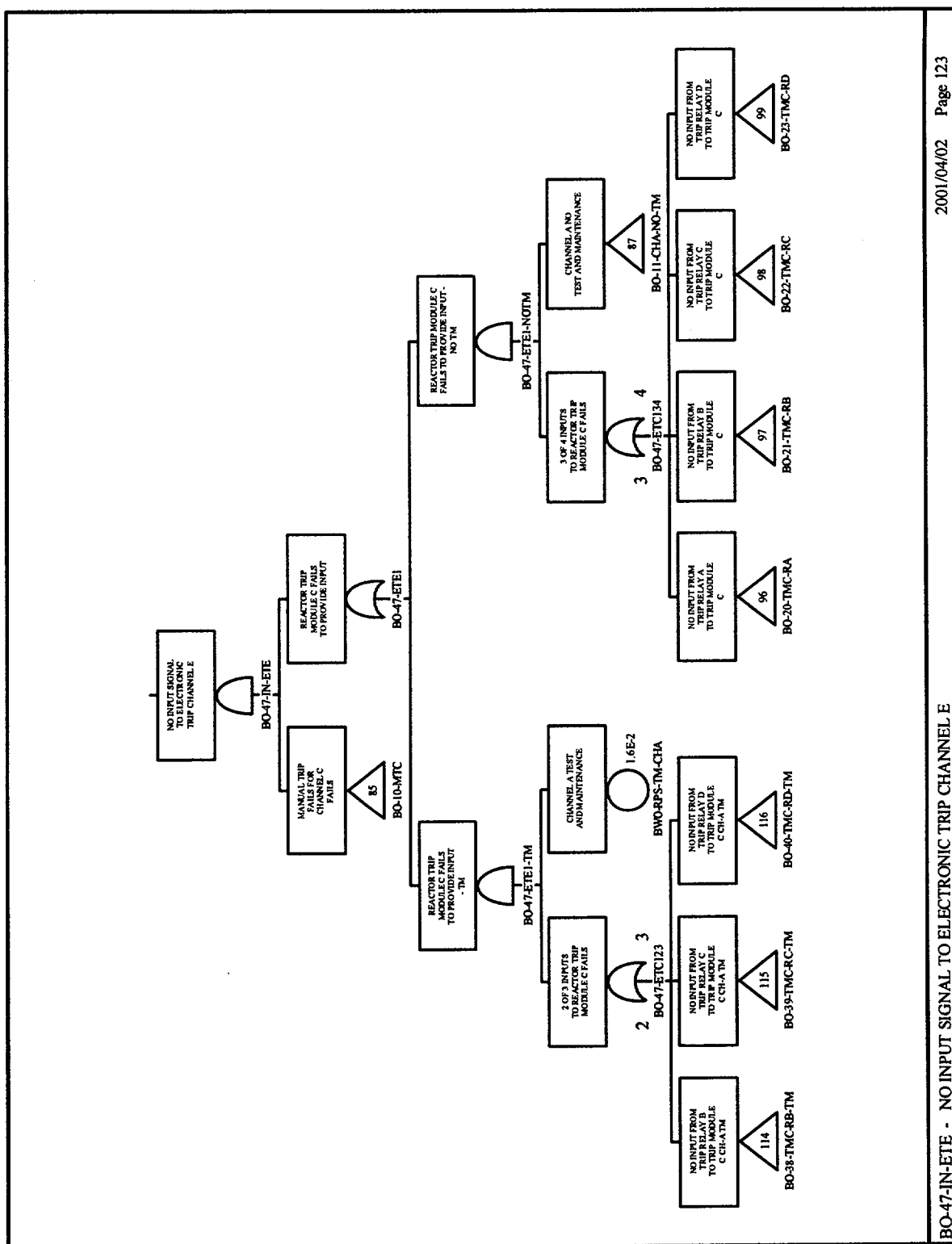


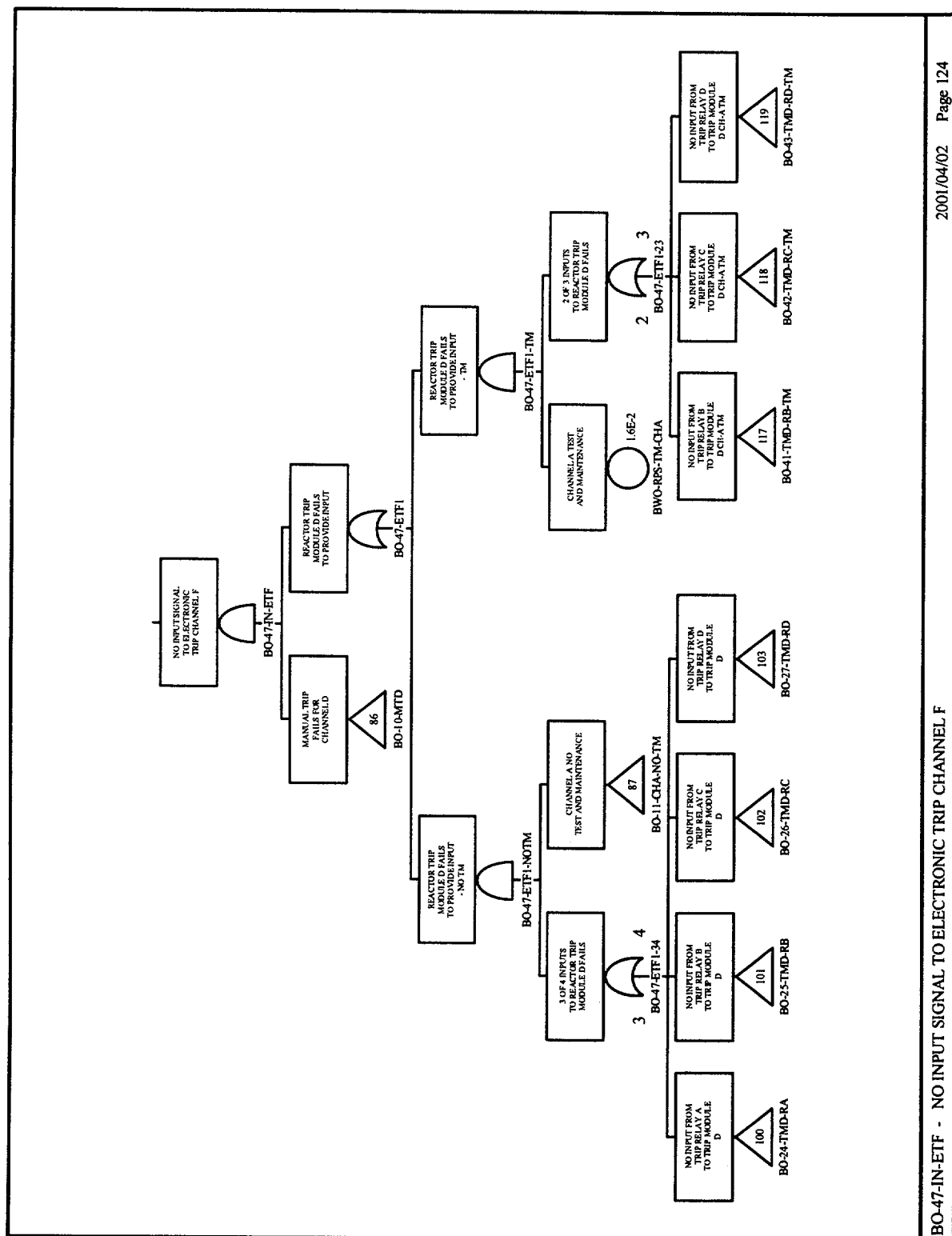




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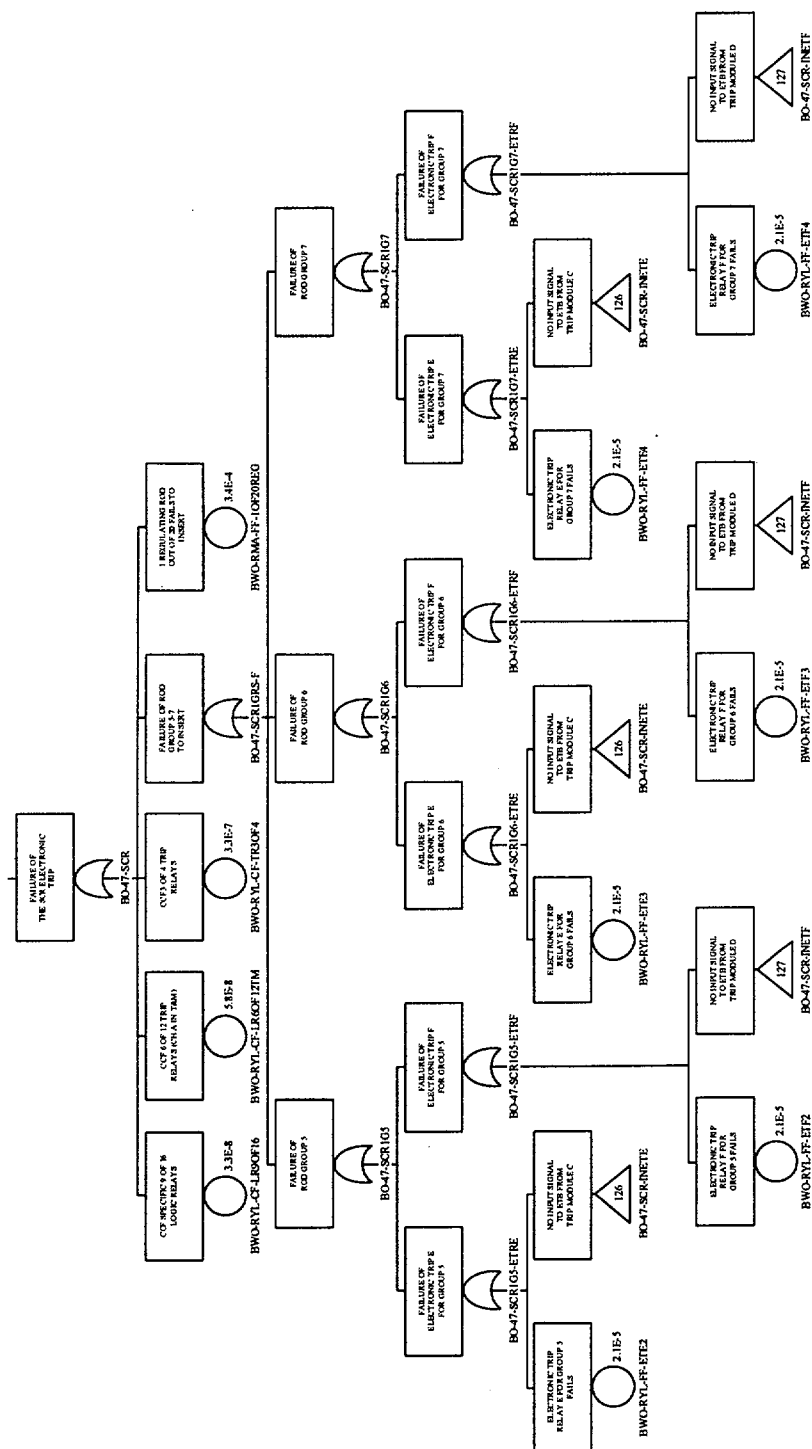


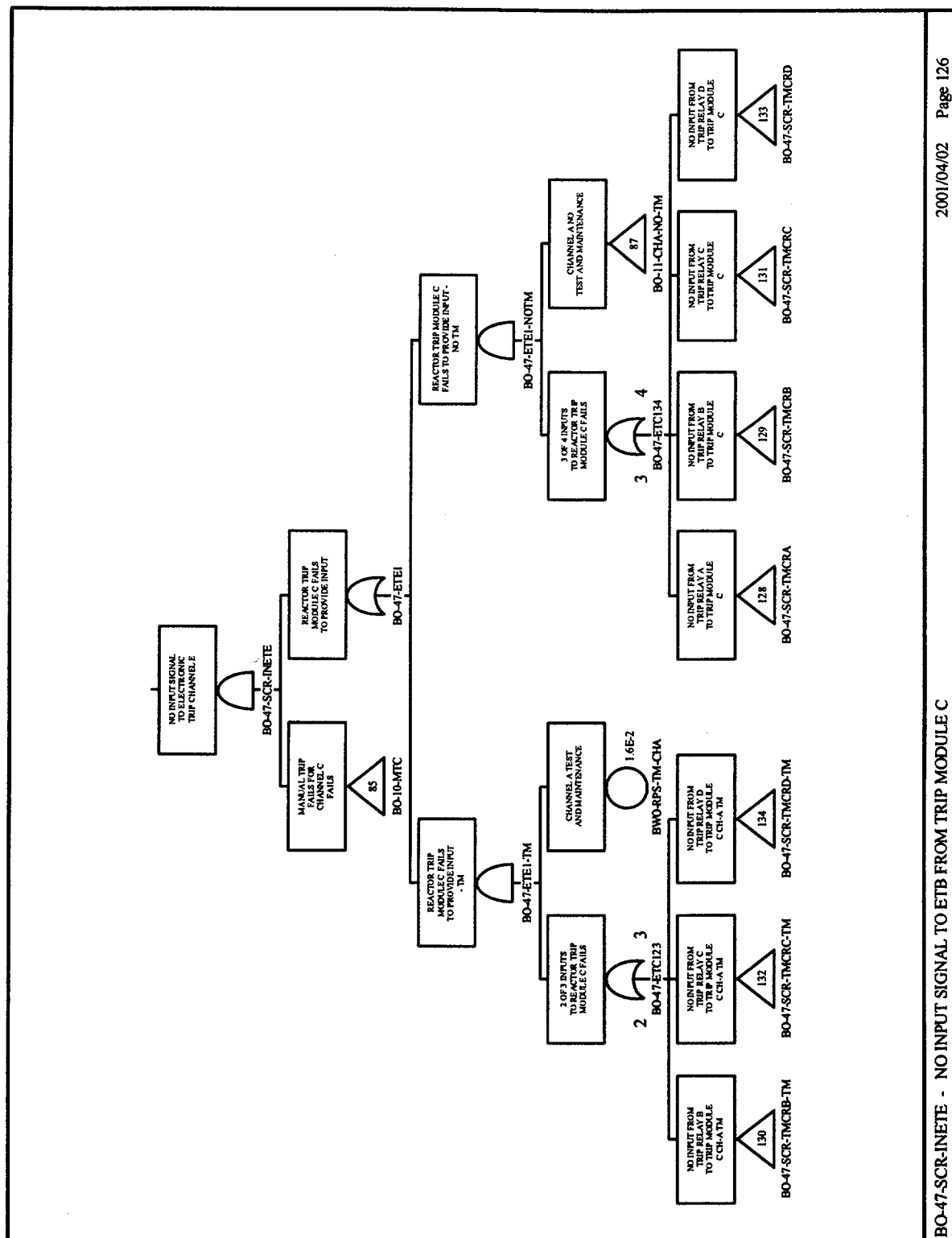


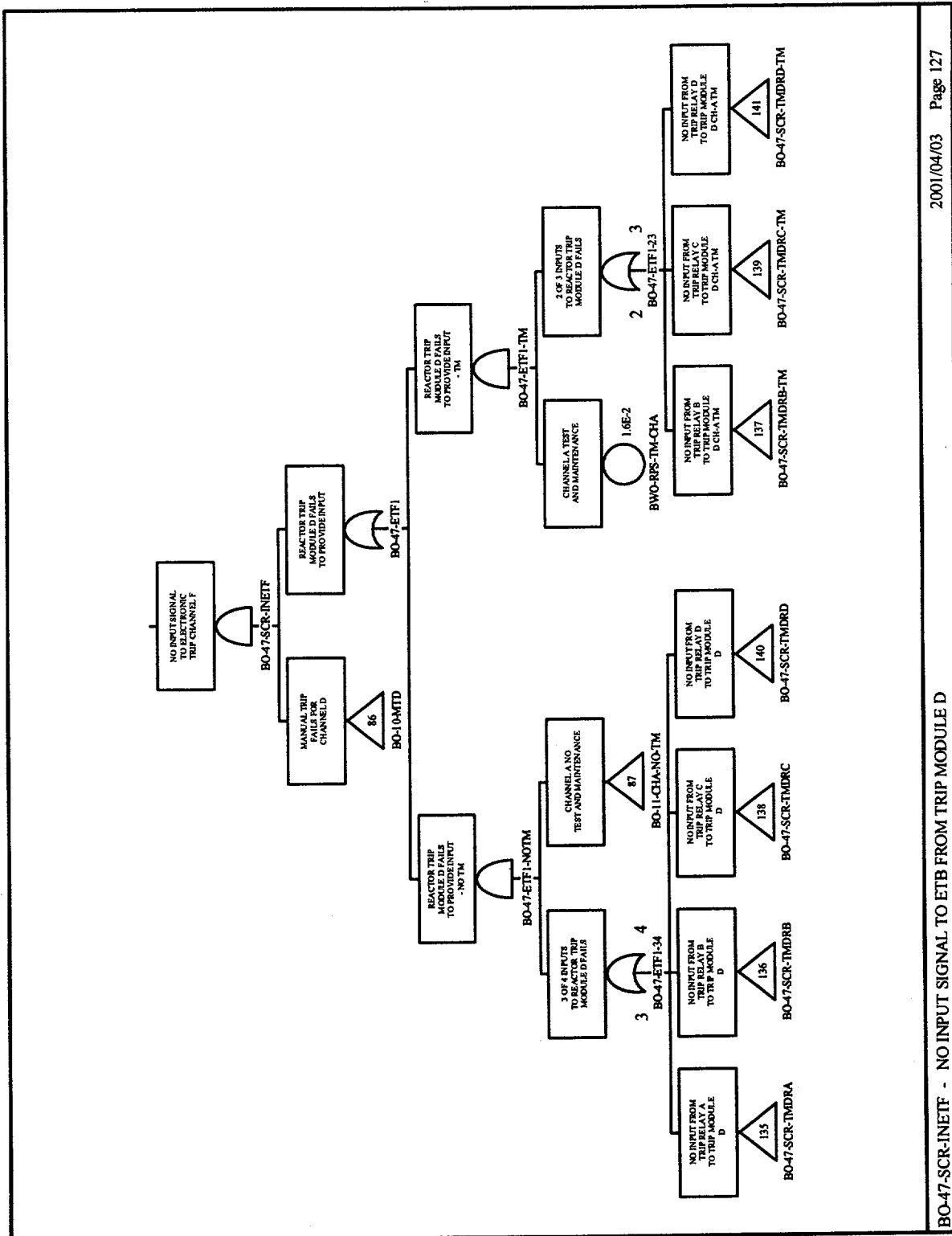


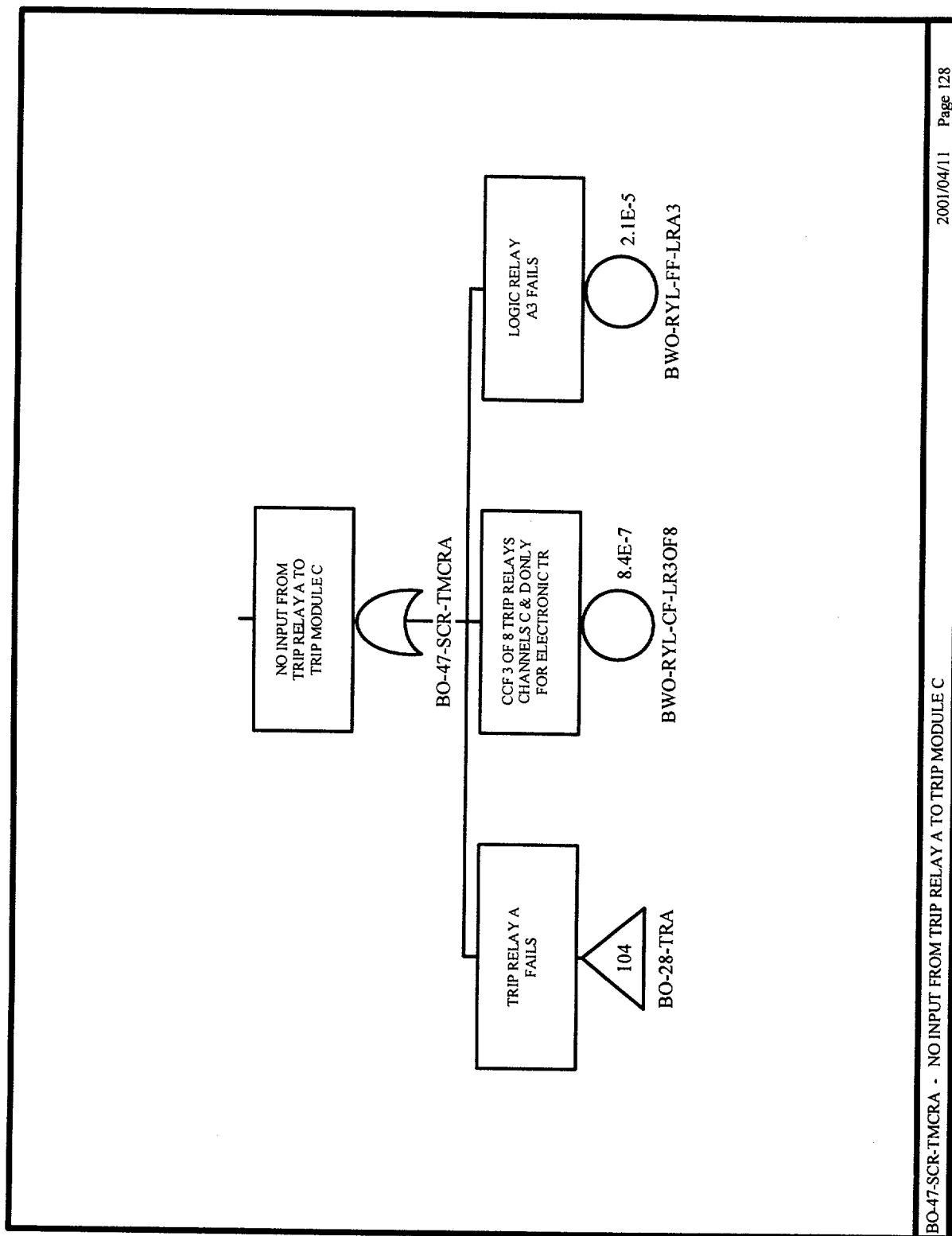
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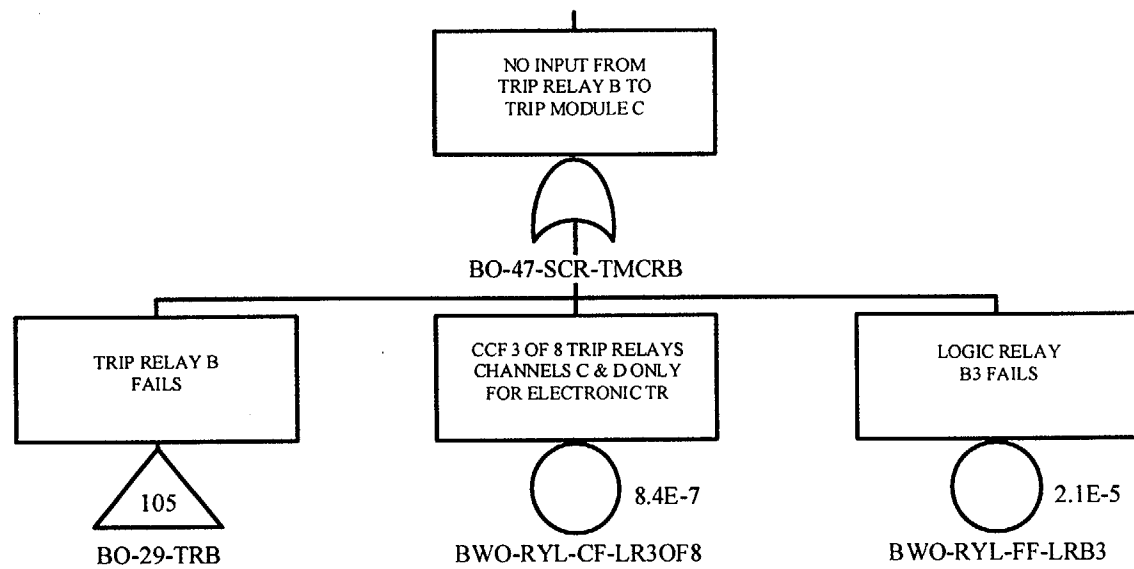
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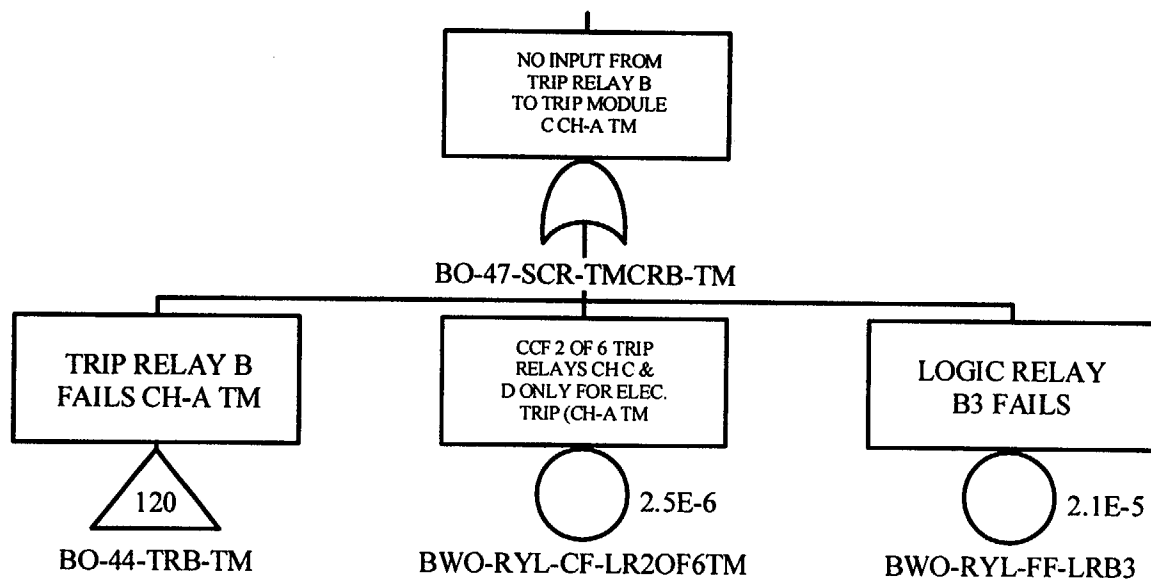


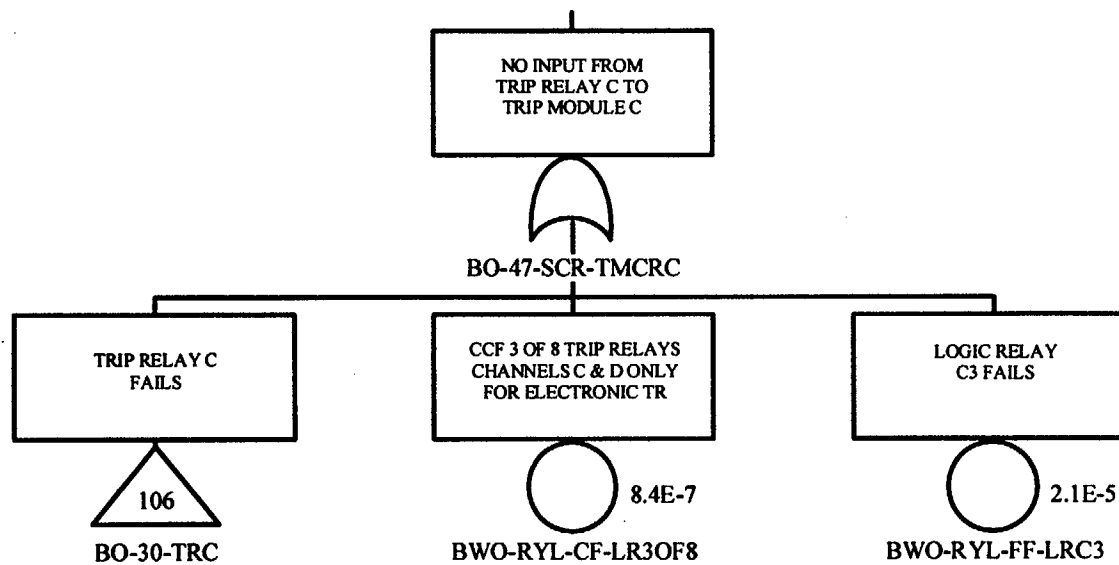


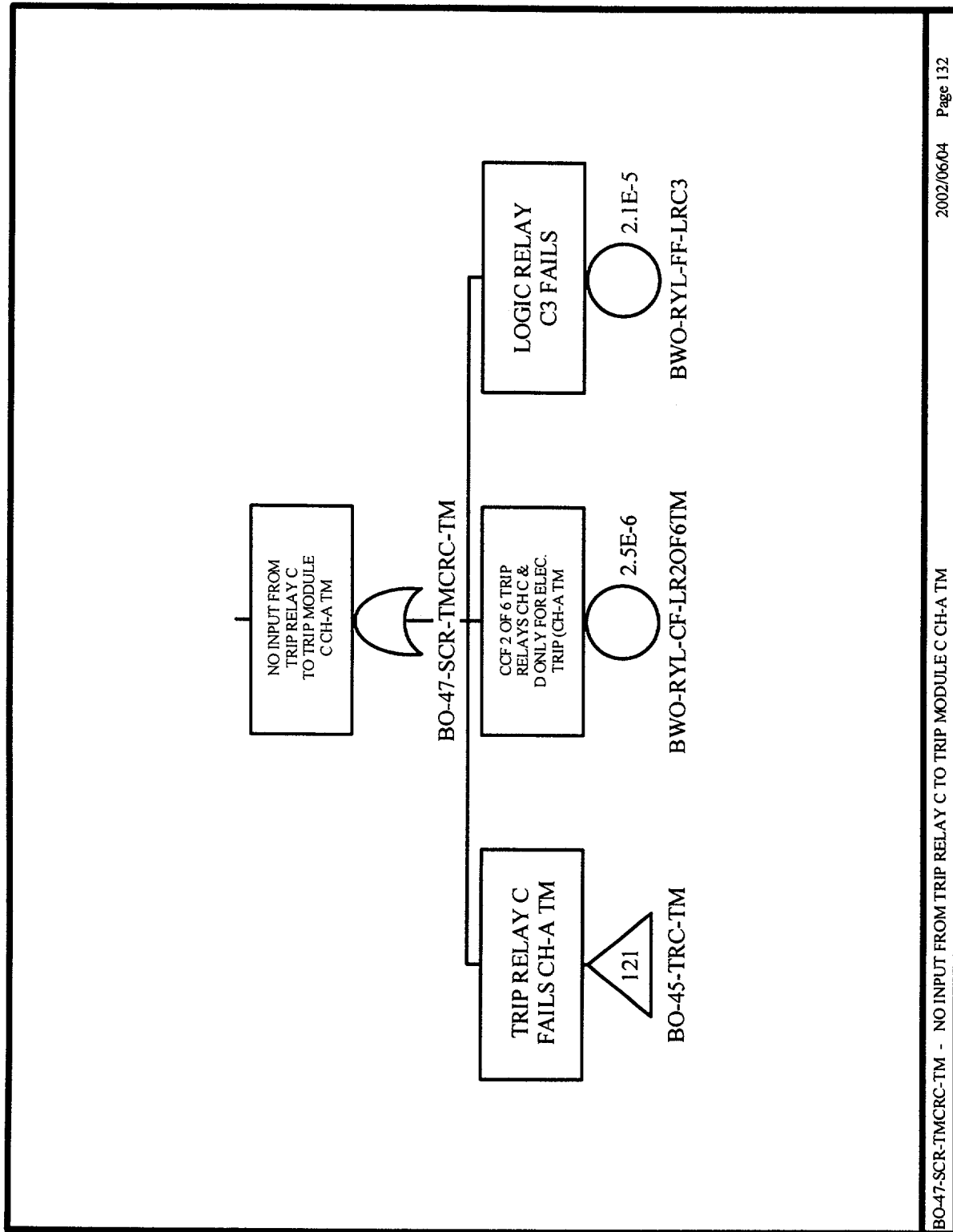


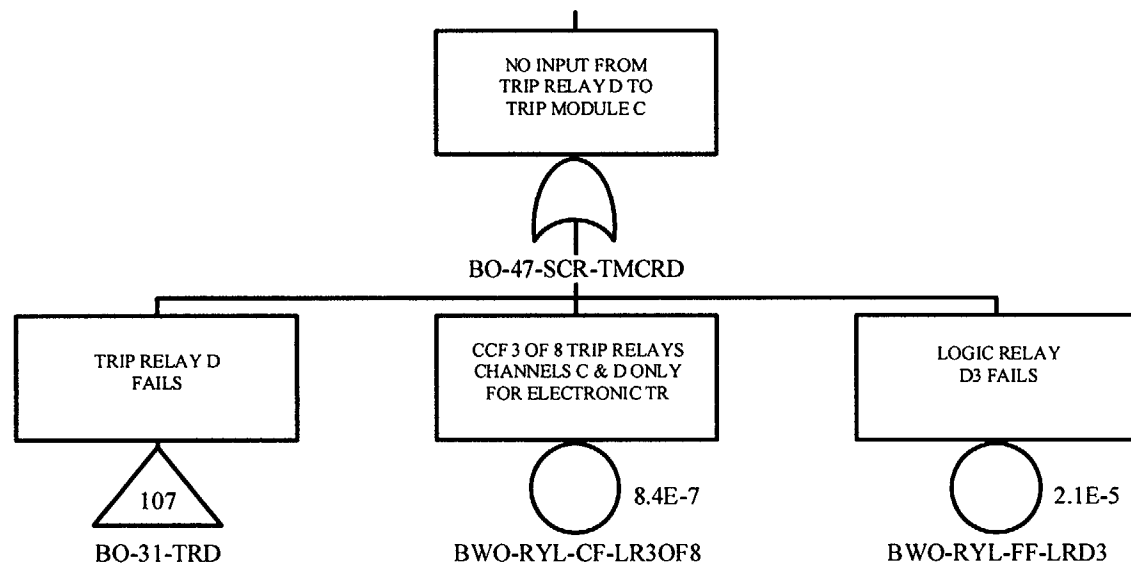


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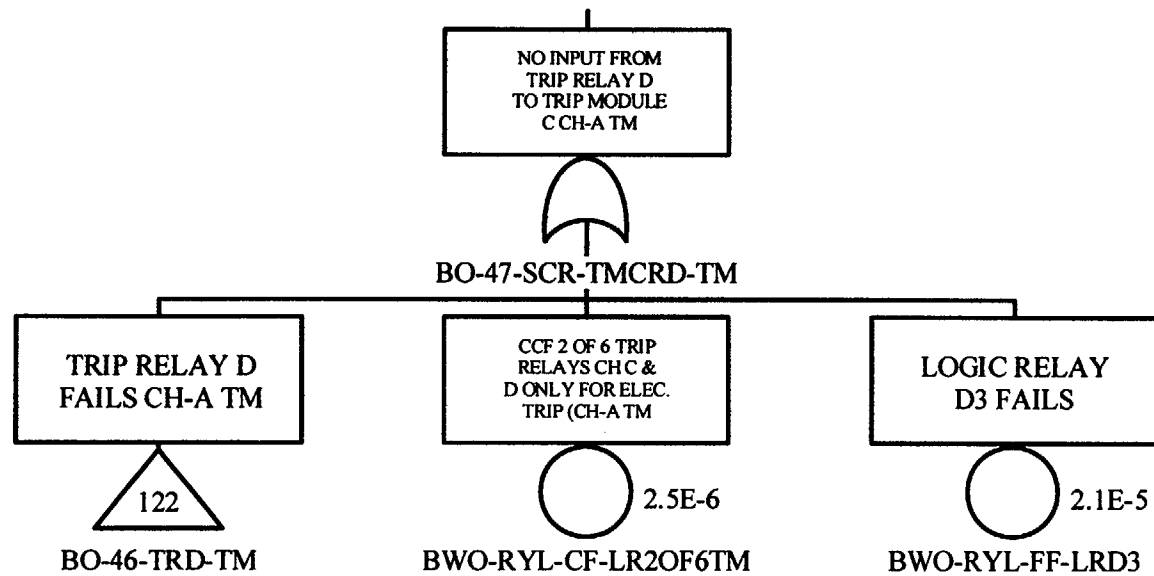


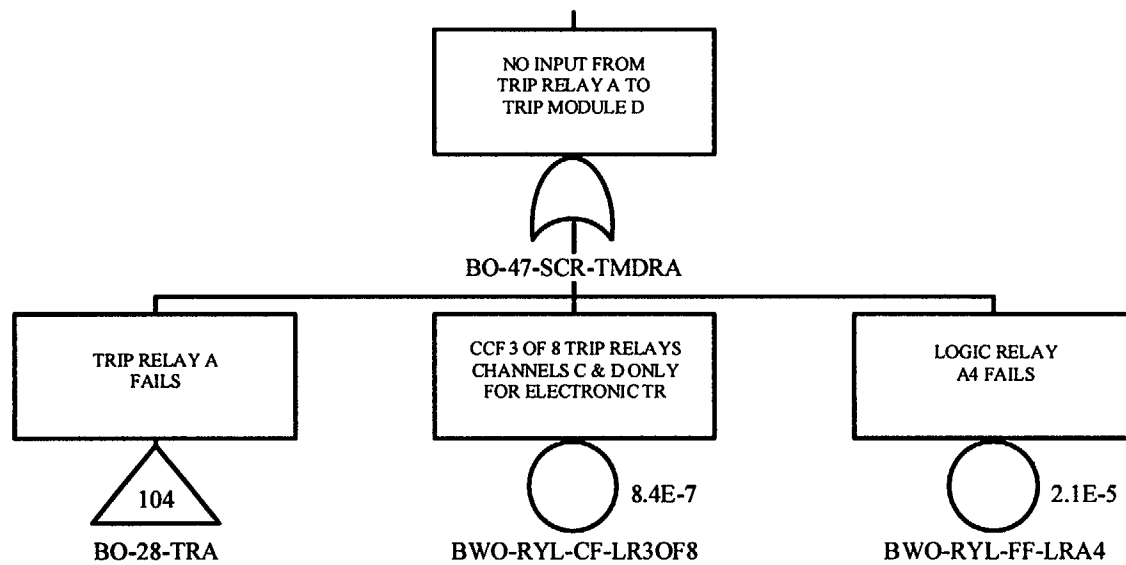


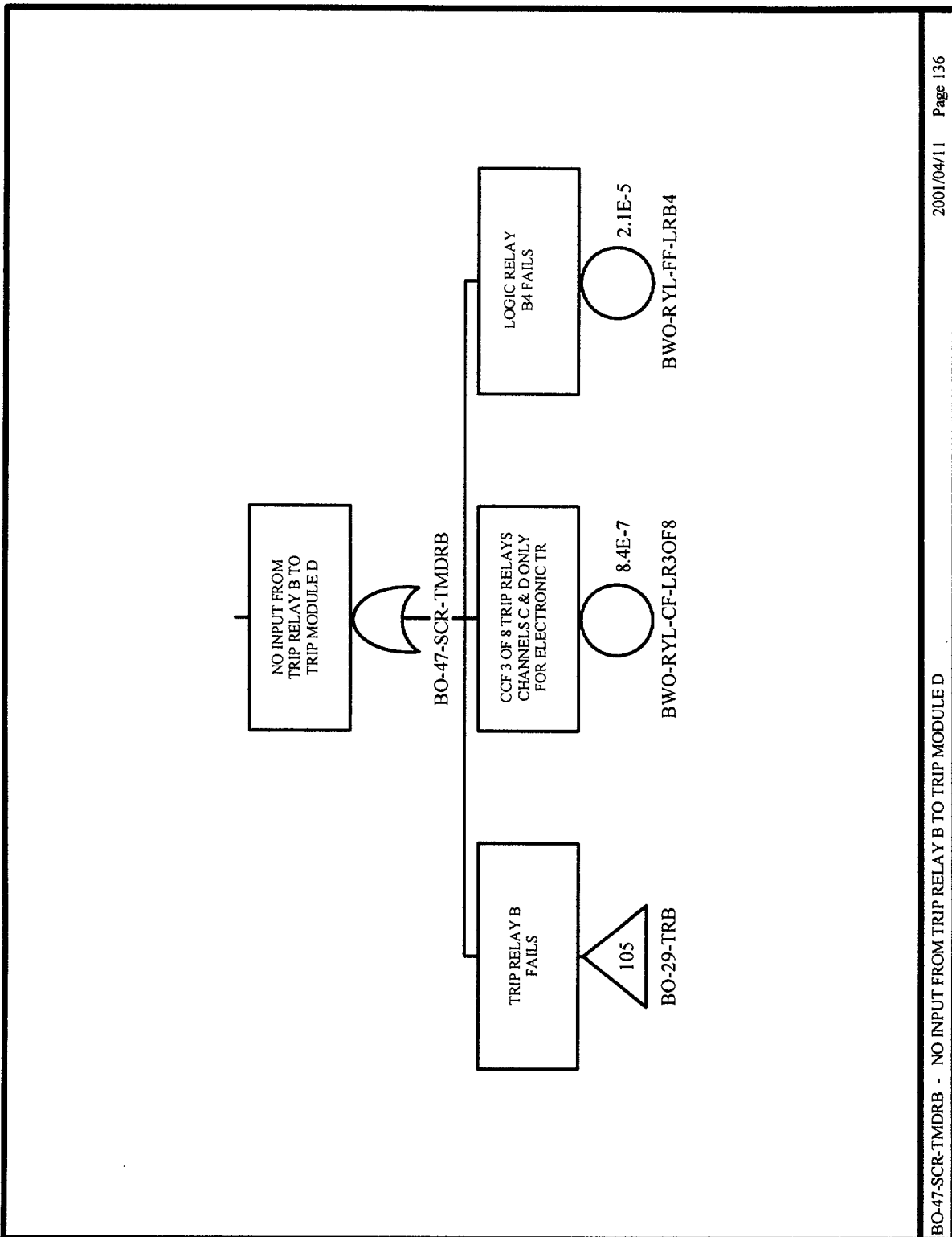


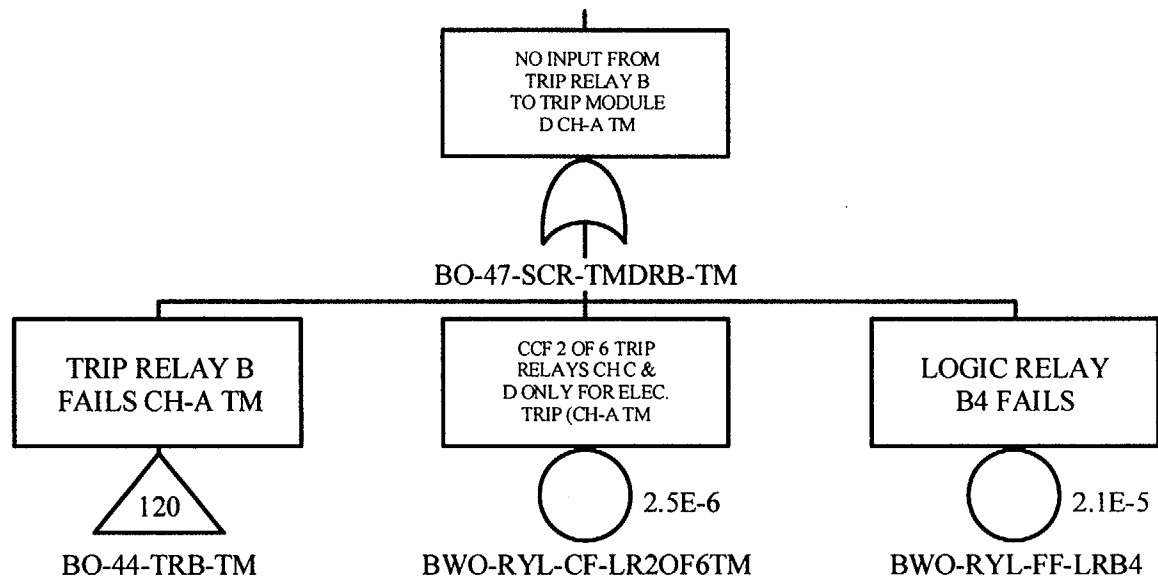


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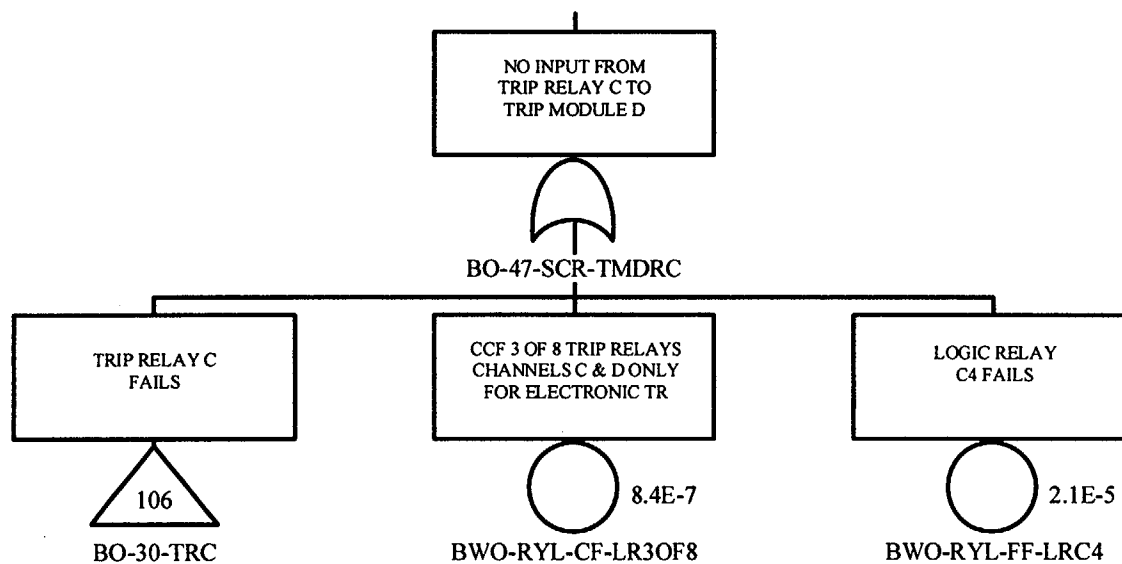


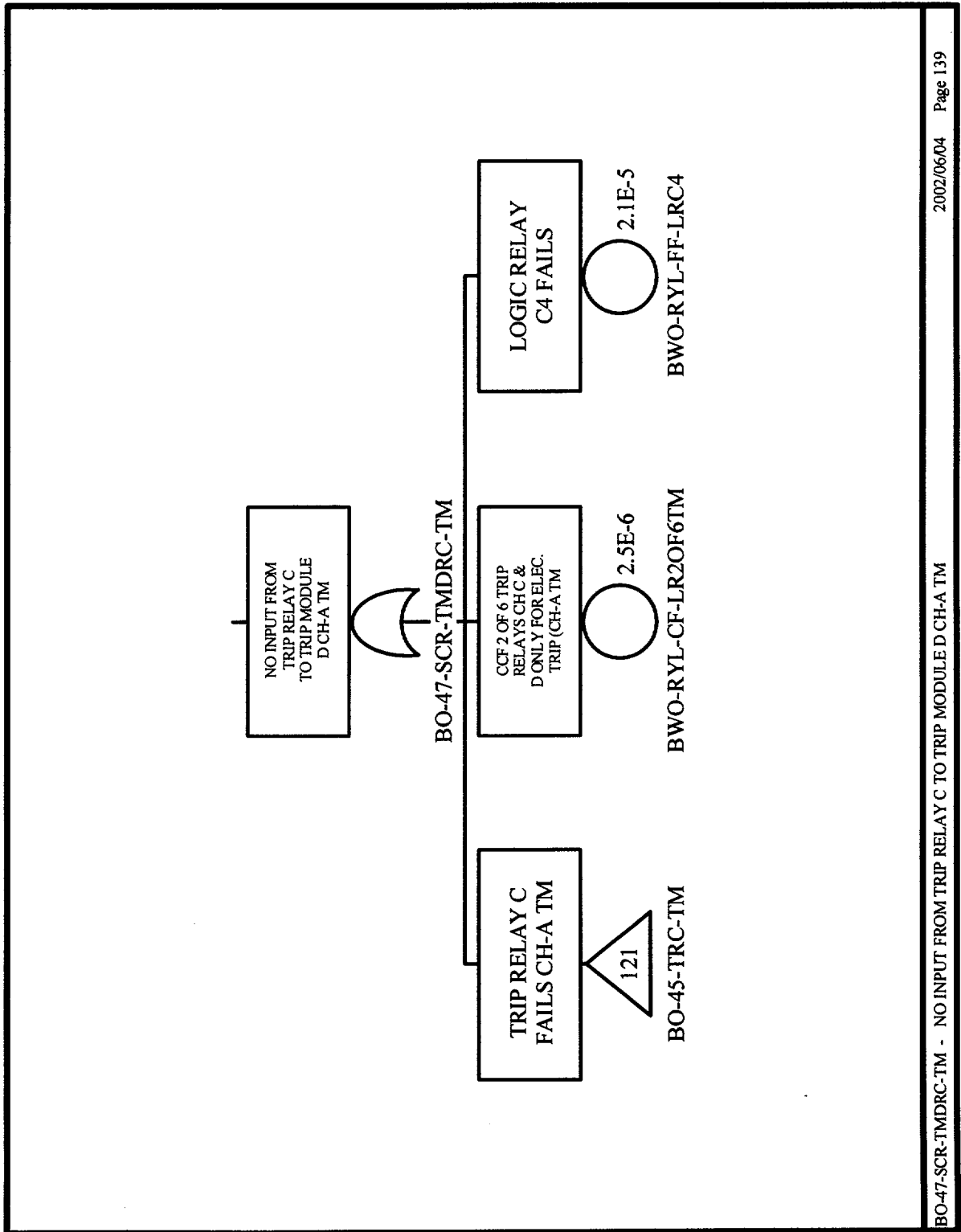




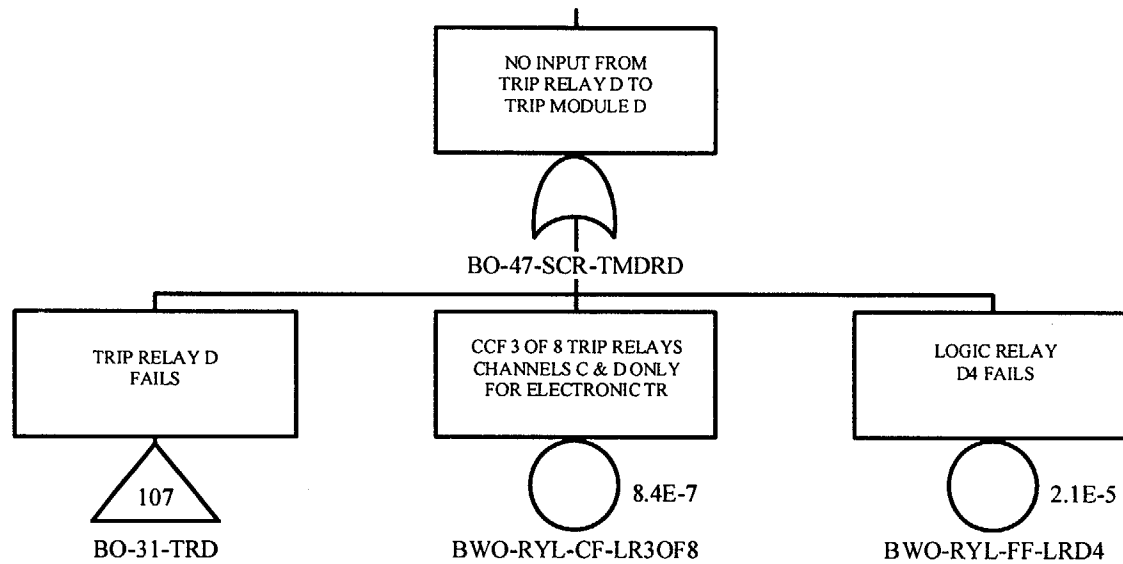


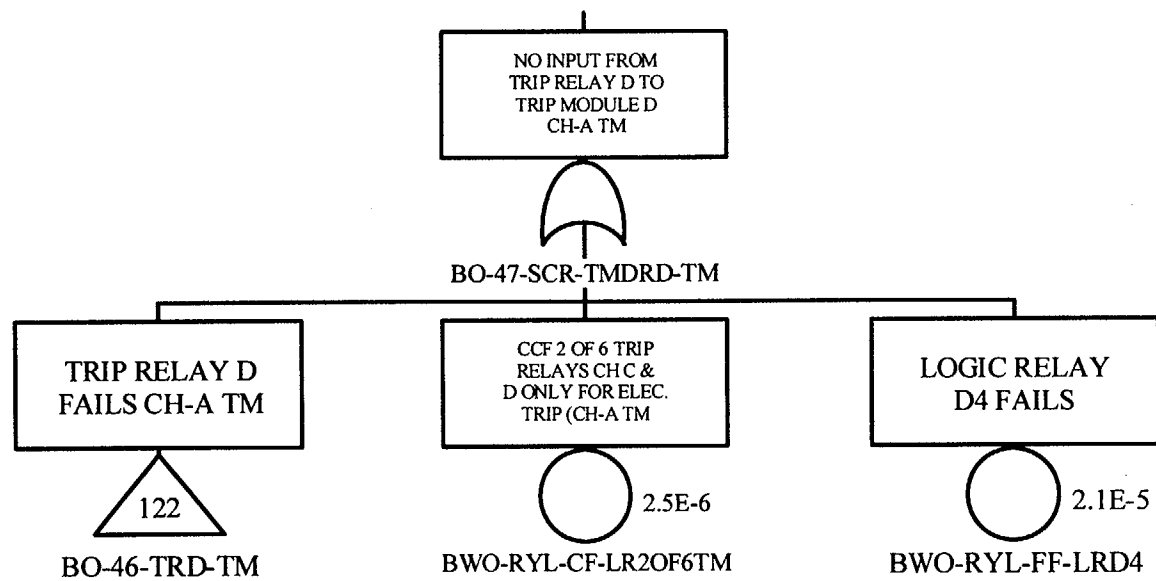
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Appendix E

Common-Cause Failure Analysis

Appendix E

Common-Cause Failure Analysis

E-1. INTRODUCTION

This appendix presents general information on common-cause failure (CCF) and special techniques developed for the reactor protection system (RPS) study. Sections discuss background, methodology, the RPS CCF database, the prior, special software developed for this study, calculation of CCF basic event (BE) probabilities, and sensitivities. Throughout the section, component codes (e.g., CPR) are used when referring to components used in the RPS study. These codes are defined in the acronym list at the beginning of this report.

E-1.1 CCF Event Definition

A CCF event consists of component failures that meet four criteria: (1) two or more individual components fail or are degraded, including failures during demand, in-service testing, or deficiencies that would have resulted in a failure if a demand signal had been received; (2) components fail within a selected period of time, such that success of the probabilistic risk assessment (PRA) mission would be uncertain; (3) component failures result from a single shared cause and coupling mechanism; and (4) component failures are not due to failures of equipment outside the established component boundary.

Two data sources are used to select equipment failure reports to be reviewed for CCF event identification. The first is the Nuclear Plant Reliability Data System (NPRDS), which contains component failure information. The second one is the Sequence Coding and Search System (SCSS), which contains Licensee Event Reports (LERs).

The CCF event identification process includes review of failure data to identify CCF events and independent failure event counts. The identification process allows the analyst to consistently screen failures and identify CCF events. The CCF event coding process provides guidance for the analyst to consistently code CCF events. Sufficient information is recorded to ensure accuracy and consistency. Additionally, the CCF events are stored in a format that allows PRA analysts to review the events and develop understanding of CCF phenomenology.

E-1.2 Approach

The calculation of a CCF BE probability is a multi-step process. The fault trees developed for the RPS study identified CCF events that contributed to the possible failure of the RPS to successfully initiate a reactor trip. The data review and calculation of those CCF BE probabilities were driven by those needs. Figure E-1 shows a process flow diagram outlining the steps necessary to calculate a CCF BE probability. The step involving analysis of failure events is discussed in Appendices A and C. Fault tree development, defining CCF BE criteria, and component boundary definitions are discussed in Section 2 of the main body of this report.

This appendix presents a brief review of the CCF calculations to familiarize the reader with the terminology. More information can be found in the report *Common-Cause Failure Database and Analysis System: Event Definition and Classification*.^{E-1}

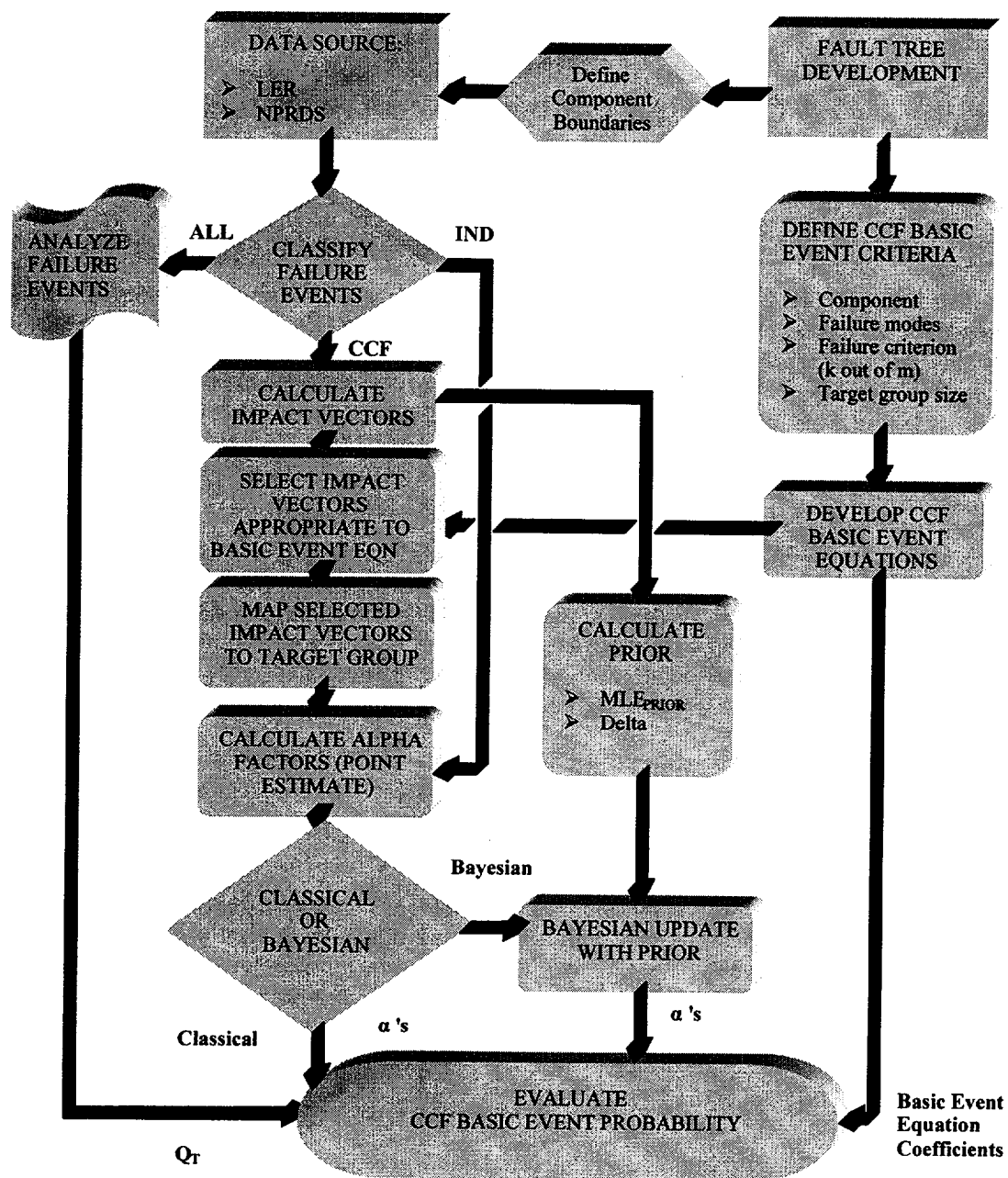


Figure E-1. CCF process flow diagram.

E-2. CCF MODEL

This section presents information on the type of CCF model used in this study and describes the process of developing the CCF BE equation.

E-2.1 Alpha Model

In order to estimate the probability of a common-cause event involving k specific components in a common-cause component group (CCCG) of size m , a model needed to be selected from among the

available models. Available models included the Basic Parameter model, the Beta model, the Multiple Greek Letter (MGL) model, and the Alpha Factor model.

The parametric Alpha Factor model was chosen because the alpha factor model (1) is multi-parameter and can handle any redundancy level, (2) is based on ratios of failure rates, which makes the assessment of its parameters easier when no statistical data are available, and (3) has a simpler statistical model, and produces more accurate point estimates, as well as uncertainty distributions, compared to other parametric models having the above two properties.

The alpha factor model estimates CCF frequencies from a set of ratios of failures and the total component failure rate. The parameters of the model are

Q_T $\equiv$ total failure probability of each component (includes independent and common-cause events)

$\alpha_k^{(m)}$ $\equiv$ fraction of the total probability of failure events that occur in the system involving the failure of k components in a system of m components due to a common-cause.

E-2.2 CCF Basic Event Equation Development

The CCF basic event probabilities are calculated using the alpha factor model. The alpha factor model requires coefficients for each alpha factor k based on the number of combinations of k components that will fail the system of components and the total number of k out of m combinations. Variations of the logic in the RPS affect the number of combinations that will fail the system of components. The first type is any k of m combinations. A special case is one-out-of-two-twice logic. Another special case of any k of m is when more than one component in a channel must fail to fail the channel, called *specific failure criterion*.

E-2.2.1 Alpha Factor Model

The form of the CCF BE equation for any k out of m components failing is given by Equation E-1 for *staggered* testing:

$$Q_{CCF} = Q_T \sum_{i=k}^m \frac{\binom{m}{i}}{\binom{m-1}{i-1}} \alpha_i^{(m)} = Q_T \sum_{i=k}^m \frac{m}{i} \alpha_i^{(m)} \quad \text{E-1}$$

where:

$\alpha_i^{(m)}$ = the ratio of i and only i CCF failures to total failures in a system of m components
 m = the number of total components in the component group
 k = the failure criteria for a number of component failures in the component group
 Q_T = the random failure probability (total)
 Q_{CCF} = the failure probability of k and greater than k components due to CCF

The BE probability for a specific k failures out of a system of m components (assuming a staggered testing scheme) is shown in Equation E-2.

$$Q_{CCF} = Q_T \sum_{i=k}^m \frac{C_i}{\binom{m-1}{i-1}} \alpha_i^{(m)} \quad \text{E-2}$$

where:

- α_i = the ratio of i and only i CCF failures to total failures
- m = the number of total rods in the component group
- k = the failure criteria for a number of rod failures in the component group
- Q_T = the random failure probability (total)
- Q_{CCF} = the failure probability of k and greater than k components due to CCF
- C_i = number of combinations of k component failures that will fail the system

E-2.2.2 Any k of m Logic

The failure criterion, any k of m , is used to represent system logic that requires k failures out of m components to fail the component system. All combinations of k of m will fail the component system. An example of this in the RPS system is the simple sensor/transmitter logic where 3 of 4 pressure transmitters will fail the high pressure trip signal to the RPS channels. Another example is the rod failure criteria, in which the rods may fail in any combination of 20 percent, or more, and the rod insertion is considered failed. The failure criterion is described in shorthand as k/m . Equation E-1 is used for these types of logic.

E-2.2.3 One-Out-of-Two-Twice Logic

An example of a one-out-of-two-twice logic failure criterion is shown in Figure E-2. This example applies to the 2/4 BME CCF event used in the fault trees. In this example, the failure criterion is described in shorthand as 2/4. This is based on failure of two of two components to fail a channel and specific failure of one of two channels to fail a train. Some of the combinations of four component failures will fail two channels, but no trains (e.g., those combinations where two failures are in each of two trains). Some combinations of four will fail an entire train. An example is shown in the failure side of Figure E-2. The valid failure combinations are counted, and the sum becomes the C_i term in Equation E-2. When a component is taken out of service for maintenance, it is placed in a non-tripped (bypassed) status. The possible combinations are counted with the component always failed. This maintenance event is described in shorthand as 1/3 |4.

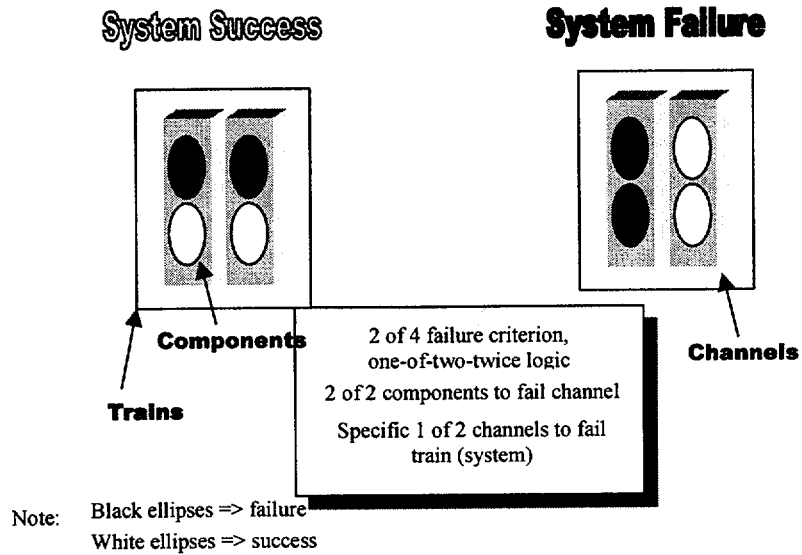


Figure E-2. Example of a one-of-two-twice logic failure criterion for a 2-out-of-4 system.

E-2.2.4 Specific Failure Criterion

An example of a specific failure criterion is shown in Figure E-3. This example applies to the 6/8 CBI CCF event used in the fault trees. In this example, the failure criterion is described in shorthand as 6/8. This is based on specific criteria of failure of two of two components to fail a channel and failure of at least three of four channels to fail the system or function. Some of the combinations of six component failures will fail three channels, e.g., those combinations where two failures are in each of three channels). Some combinations of six will fail only two channels, e.g., those combinations that have less than two failures in a channel. The valid failure combinations are counted, and the sum becomes the C_i term in Equation E-2. When a channel is taken out of service for maintenance, it is placed in a non-tripped status. The criteria then become two of two components and two or more of the remaining three channels. This maintenance event is described in shorthand as 4/6 | 8.

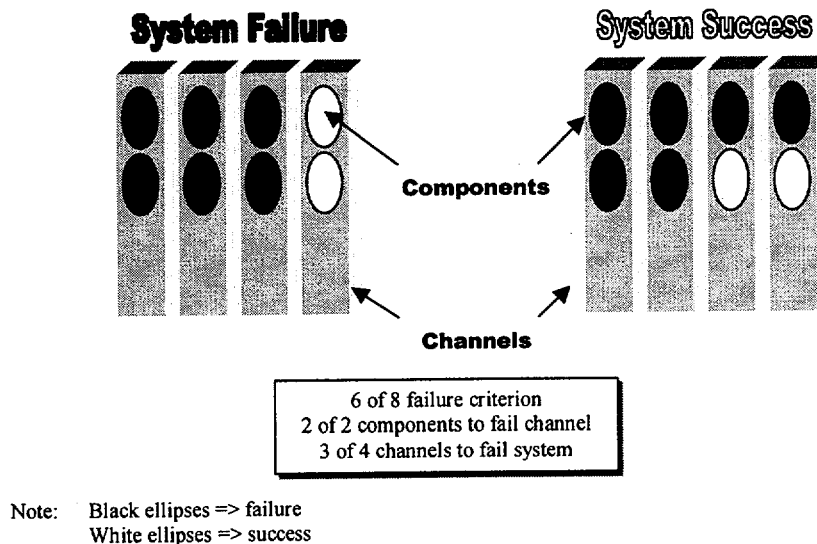


Figure E-3. Example of a specific failure criterion.

Appendix E

A subset of *specific failure criterion* is *unique failure criterion*. Unique failure criteria are calculated according to Equation E-2 using terms C_i that are counted by hand to satisfy less obvious failure criteria. CCF basic event equation 2/6 U describes the CCF of two or more trip breakers that cause the failure to remove power from two or four safety rod groups.

E-2.2.5 CCF BE Probability Equations

Table E-1 shows the CCF BE probability equations used in the B&W RPS Study. All of the equations are based on staggered testing.

Table E-1. Failure criteria and basic event equation table.

Failure Criteria			
Channel or Train Level	Component (within channel or train)	Shorthand Criterion ^a	Basic Event Probability Equations
1/2	2/2	2/4 ^b	$(\alpha_4 + 4/3 \alpha_3 + 2/3 \alpha_2) * Q_T$
3/4	1/1	3/4	Equation E-2
3/4	1/1	2/3 4	Equation E-2
3/4	2/2	4/6 8 ^c	$(\alpha_8 + 8\alpha_7/7 + 16\alpha_6/21 + 12\alpha_5/35 + 3\alpha_4/35) * Q_T$
3/4	2/2	6/8 ^c	$(\alpha_8 + 8\alpha_7/7 + 4\alpha_6/21) * Q_T$
1/2	3/4	3/8 ^c	$(\alpha_8 + 8\alpha_7/7 + 28\alpha_6/21 + 56\alpha_5/35 + 34\alpha_4/35 + 8/21 \alpha_3) * Q_T$
3/4	3/4	9/16 ^c	$(\alpha_{16} + 16\alpha_{15}/15 + 120\alpha_{14}/105 + 560\alpha_{13}/455 + 1604\alpha_{12}/1365 + 2352\alpha_{11}/3003 + 1216\alpha_{10}/5005 + 256\alpha_9/6435) * Q_T$
3/4	3/4	6/12 16 ^c	$(\alpha_{16} + 16\alpha_{15}/15 + 120\alpha_{14}/105 + 560\alpha_{13}/455 + 1712\alpha_{12}/1365 + 3360\alpha_{11}/3003 + 4180\alpha_{10}/5005 + 3256\alpha_9/6435 + 1539\alpha_8/6435 + 408\alpha_7/5005 + 48\alpha_6/3003) * Q_T$
3/4	3/3	9/12 ^c	$(\alpha_{12} + 12\alpha_{11}/11 + 12\alpha_{10}/55 + 4\alpha_9/165) * Q_T$
3/4	3/3	6/9 12 ^c	$(\alpha_{12} + 12\alpha_{11}/11 + 39\alpha_{10}/55 + 58\alpha_9/165 + 45\alpha_8/330 + 18\alpha_7/462 + 3\alpha_6/462) * Q_T$
8/41	1/1	8/41	Equation E-2
2/6	1/1	2/6 U ^a	$(\alpha_6 + 6/5 \alpha_5 + 14/10 \alpha_4 + 14/10 \alpha_3 + 4/5 \alpha_2) * Q_T$

a. Shorthand criteria with the form x/y | z are maintenance events involving one channel or train taken out of service due to maintenance. Shorthand criteria in the form x/y Ux are unique calculations and are described in Section E-2.2.4.

b. This criterion is based on the one-out-of-two logic described in Section E-2.2.3.

c. This criterion is based on the specific failure criterion described in Section E-2.2.4.

E-3. CCF PARAMETER DEVELOPMENT

This section discusses in detail the parameters, tools, and treatments developed specifically for the RPS study. Specifically, it describes the development of a PWR RPS-specific prior, how CCF BE probabilities are calculated, application of the safety function knowledge, and special application of the Bayesian update process.

E-3.1 CCF Calculation Methodology

Three techniques are discussed in this section. These techniques are used to facilitate the estimation of plant-specific CCF probabilities from industry experience. One technique is the *impact vector* method, which is used to classify events according to the level of impact of common-cause events and the associated uncertainties in numerical terms. The second is impact vector specialization, in which

impact vectors are modified to reflect the likelihood of the occurrence of the event in the specific system of interest. This technique is called *mapping*. The third technique is the estimation of alpha factors from the mapped impact vectors. Each technique is described briefly. More information on CCF methodology can be found in NUREG/CR-5485.^{E-2}

E-3.1.1 Impact Vector

An impact vector is a numerical representation of a CCF event. For a CCCG of size m , an impact vector has $m+1$ elements. The $k+1$ element, denoted by F_k , equals one if failure of exactly k components occurred, and zero otherwise. This applies to those situations where the component degradation values equal 1.0 and the time delay and coupling strength are 1.0. For those cases where these parameters are less than 1.0, the following techniques are used to develop an impact vector.

E-3.1.1.1 Impact Vector Equations. The values of the different elements (F_k) of the impact vector can be calculated based on the possible combinations of failures and non-failures. Equation E-4 shows, in general, how an element of the impact vector is calculated based on a degraded component state:

$$F_k^{(m)} = \sum_{l=0}^{\binom{m}{k}} \prod_{i=0}^k (p_i) \prod_{j=0}^{m-k} (1 - p_j) \quad \text{E-4}$$

where:

m	=	the number of elements in the group
k	=	the number of failures out of the group of m
i	=	the failure elements of the l^{th} combination of k out of m failures
j	=	the non-failure elements of the l^{th} combination of k out of m failures
p	=	the weight or probability of the failure of each component (component degradation value)

Two additional parameters are coded with each CCF event: q represents the timing factor, and c represents the shared cause factor. The impact vector is then modified to reflect these parameters in the following manner:

$$\begin{aligned} I_{CCF} &= [cqF_0^{(m)}, cqF_1^{(m)}, \dots, cqF_m^{(m)}] \\ I_{c_1} &= [(1 - cq)(1 - p_1), (1 - cq)p_1, 0, \dots, 0] \\ &\vdots \\ I_{c_m} &= [(1 - cq)(1 - p_m), (1 - cq)p_m, 0, \dots, 0] \end{aligned} \quad \text{E-5}$$

where:

c	=	shared cause factor
q	=	timing factor

Finally, the average impact vector is obtained by adding I_{CCF} and the I_c 's, element by element.

E-3.1.1.2 Treatment of Uncertainty in Determining the Loss of Component Safety Function. During the review of the NPRDS and LER data for the RPS study there was some uncertainty about whether the safety function of the piece of equipment under scrutiny was compromised due to the failure mechanism. The uncertainty in this judgment is due to either (1) unclear text in the

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event narrative, or (2) the component could be required to perform in different modes in the fault trees. For example, if a temperature detector fails high, it could either cause a spurious trip or contribute to preventing a trip, depending on the parameter being measured.

To document the safety function impact, an additional field (FM2) was added to the database. When the analyst was uncertain about the status of the safety function, UKN (unknown) was entered in this field. Otherwise the field was coded FS for a fail-safe failure mode or NFS for a non-fail-safe failure mode.

This information was used in estimating component failure rates or Q_T 's in Appendix C. The method is to calculate a ratio (NFS Ratio) of the failures identified as NFS to those that are identified as either FS or NFS. The NFS ratio was then applied by multiplying the count of UKN events by the NFS ratio and adding that to the NFS count.

The CCF data were treated in a similar manner. The method chosen to implement this treatment is to multiply each element of the average impact vector (for those CCF events designated as UKN) by the NFS ratio the same as the treatment of coupling strength and time delay. This effectively provides consistency between the CCF alpha parameter calculation and the Q_T calculation. A list of the component-specific ratios is given in Table E-2.

$$NFS\ Ratio = \frac{NFS + 0.5}{NFS + FS + 1.0}$$

Table E-2. Component NFS ratios.

Component	FS Count	NFS Count	NFS Ratio
BME	255	37	0.13
BSN	15	19	0.56
BUV	71	91	0.56
CBI	448	583	0.57
CPR	234	287	0.55
CTP	199	226	0.53
RYT	20	13	0.40
RYL	20	5	0.21
ROD	1	12	0.89

E-3.1.2 Mapping of Data

E-3.1.2.1 Exposed Population versus Component Group Size. There is a difference between the concepts of exposed population and the CCCG size. The exposed population is a data analysis concept, and CCCG size is a modeling concept. An example of the difference is provided in the context of the RPS study.

PWR plants contain up to 40 bistables in the RPS. In most cases, the actual number of installed bistables in a particular plant represents the exposed population. This would apply to failures due to design faults and setpoint drift. Table A-2 shows the installed population count basis used in this study. In some cases, the exposed population can be less than the installed population. This would apply to the failure of several bistables in one channel, due to inadequate cooling.

For a given trip scenario, one or more bistables are required to function in each channel. The CCCG size is the number of bistables required per channel times the number of channels. This varies as the number of modeled trip parameters changes, depending upon the channel design. Therefore, it is possible to have events with in-plant populations of up to 24 components, and the modeled events have a CCCG from two up to the exposed population.

An impact vector represents a CCF event in a specific group of components of exposed population size m . A collection of impact vectors used to calculate the CCF BE probability for a particular component may contain impact vectors of many different exposed population sizes (e.g., events that occur in different plants or different systems). In this case, the impact vectors are mapped to the CCCG size of interest.

E-3.1.2.2 Mapping Techniques. An impact vector will be mapped up, mapped down, or unchanged depending upon the relationship between the original system and the target system CCCG. The process for determining the equations for mapping has been written into a program to allow mapping from any size system to any other size system. The equations that describe the mapping process are discussed below.

There are three general routines for mapping, depending on the relationship between the original impact vectors and the system of interest. Mapping down is performed when the impact vector exposed population size is larger than the target group size, and mapping up is performed when the impact vector exposed population size is smaller than the target group size. In the special case where the impact vector has been coded as a "lethal shock," the impact vector for the new system of m components contains a 1.0 in the F_m position. To illustrate the mapping process, mapping down and mapping up equations are presented for CCCGs of three and five in Equations E-6 and E-7.

Mapping Down ($5 \Rightarrow 3$)

$$\begin{aligned} F_1^{(3)} &= 3/5 F_1^{(5)} + 3/5 F_2^{(5)} + 3/10 F_3^{(5)} \\ F_2^{(3)} &= 3/10 F_2^{(5)} + 3/5 F_3^{(5)} + 3/5 F_4^{(5)} \\ F_3^{(3)} &= 1/10 F_3^{(5)} + 2/5 F_4^{(5)} + F_5^{(5)} \end{aligned} \quad \text{E-6}$$

Mapping Up ($3 \Rightarrow 5$)

$$\begin{aligned} F_1^{(5)} &= 5/3(1 - \rho)^2 F_1^{(3)} \\ F_2^{(5)} &= 7/3\rho(1 - \rho)^1 F_1^{(3)} + (1 - \rho)^2 F_2^{(3)} \\ F_3^{(5)} &= \rho^2 F_1^{(3)} + 2\rho(1 - \rho)^1 F_2^{(3)} + (1 - \rho)^2 F_3^{(3)} \\ F_4^{(5)} &= \rho^2 F_2^{(3)} + 2\rho(1 - \rho)^1 F_3^{(3)} \\ F_5^{(5)} &= \rho^2 F_3^{(3)} \end{aligned} \quad \text{E-7}$$

The parameter ρ in Equation E-7 is called the *mapping up* parameter. It is the probability that the non-lethal shock or cause would have failed a single component added to the system. One equation for estimating ρ is given by Equation E-8^{E-3}

$$\rho = \frac{\sum_{i=1}^m i(i-1)f_i}{(m-1)\sum_{i=1}^m i(f_i)} \quad \text{E-8}$$

where

m = the number of elements in the group (CCCG)
 f_i = the i^{th} element of the generic impact vector.

This method works well when the system sizes are close to one another (e.g., mapping from size 2 to size 3 or 4) or when at least one of the component degradation values is less than 1.0. When all of the component degradation values are equal to 1.0, ρ is also equal to 1.0. When used in the *mapping up* equations for the RPS data, this method tends to overestimate the probability that components added to a system will exhibit the same lethal shock-like behavior. Examination of trends in the unmapped RPS data shows that as the number of components in a system increases, the likelihood of lethal behavior in that group of components decreases rapidly. Based on these observed trends and empirical studies, a value of 0.85 was established for ρ .

E-3.1.3 Estimation of CCF Alpha Factors

Once the impact vectors are calculated for the target group, the number of events in each impact category (n_k , Equation E-9), can be calculated by adding the corresponding elements of the impact vectors. That is, with n CCF events,

$$n_k = \sum_{j=1}^n F_k(j) \quad \text{E-9}$$

where:

$F_k(i)$ = the k^{th} element of the impact vector for event i .

The parameters of the alpha-factor model, Equation E-10, can be estimated using the following maximum likelihood estimators (MLE):

$$\alpha_i^{(m)} = \frac{n_k}{\sum_{k=1}^m n_k} \quad \text{E-10}$$

E-3.2 Development of an RPS-Specific Prior Distribution

E-3.2.1 Background

The Bayesian approach utilizes the concept of a prior distribution. The prior reflects the analyst's the current evidence about the parameter before the data are collected. In this study, the prior distribution is developed using a generic data set that is combined in a given way to produce the prior distribution. This prior is then updated with the specific component CCF data. The updated distribution is known as the posterior distribution. The posterior represents the best knowledge about the parameter after incorporating the current evidence.

E-3.2.2 PWR RPS CCF Prior Event Population

For this study, prior distributions were developed based on the common-cause data collected during the course of the RPS studies. The resultant priors represent generic data, which are updated with component specific evidence in the Bayesian update.

The RPS prior uses components from the PWR vendors. Thus, there is a large variation in the group sizes. These group sizes range from 2 to 130 with the average group size equal to 23.7.

The Babcock & Wilcox specific CCF data set only contains four CCF events, which is insufficient to build a stable prior. Therefore, the Babcock & Wilcox, Combustion Engineering, and Westinghouse RPS CCF events were pooled together and used in the estimation of the prior distributions for this study. This pooled RPS data set contains 366 CCF events.

E-3.2.3 Prior Distribution Mean Values

The Babcock & Wilcox, Combustion Engineering, and Westinghouse CCF data were mapped to a CCCG of size 2. This data set was then used to estimate the prior distributions for this CCCG size. This process was continued for CCCG sizes of 3 to 24 and 41. Table E-3 shows the sums of each element (n_k) of the impact vectors for each CCCG, which are the results of the mapping. Table E-4 shows the maximum likelihood estimators (MLE) for each component CCCG size. The MLE is estimated by Equation E-11:

$$MLE_i = \frac{n_i}{\sum_{j=1}^m n_j} \quad \text{E-11}$$

where

- m = CCCG
- n_j = the sum of the j^{th} element of the impact vector, over all events
- n_1 = sum of the first element and the Adjusted Independent
- Adjusted Independent = (Ind. Event Count * Mapped CCCG)/Average CCCG.

The CCF prior distributions for RPS system, derived from the complete set of Babcock & Wilcox, Combustion Engineering, and Westinghouse RPS data, provide initial estimates for each $\alpha^{(m)}_k$ by mapping the data to each CCCG of interest, summing the impact vector elements for each CCF event, adding the number of independent events for the CCCG being considered to the $\alpha^{(m)}_1$ term, and normalizing across the alphas for the CCCG so that they add up to one. These estimates are taken to be the mean values for each prior distribution.

Table E-3. PWR RPS prior, sums of impact vector elements.

Group Size	Adjusted Independents	Prior Σn_k Vector
2	144.2	[6.01e+01, 5.80e+00]
3	216.2	[7.91e+01, 1.12e+01, 1.96e+00]
4	288.3	[9.56e+01, 1.52e+01, 4.36e+00, 9.34e-01]
5	360.4	[1.10e+02, 2.00e+01, 5.75e+00, 2.01e+00, 6.88e-01]
6	432.5	[1.22e+02, 2.42e+01, 7.99e+00, 2.52e+00, 1.22e+00, 5.55e-01]
7	504.5	[1.33e+02, 2.84e+01, 9.58e+00, 3.74e+00, 1.43e+00, 8.81e-01, 4.60e-01]
8	576.6	[1.43e+02, 3.24e+01, 1.11e+01, 5.05e+00, 1.81e+00, 1.02e+00, 6.96e-01, 3.85e-01]
9	648.7	[1.51e+02, 3.66e+01, 1.25e+01, 5.81e+00, 2.68e+00, 1.20e+00, 7.95e-01, 5.80e-01, 3.25e-01]
10	720.8	[1.59e+02, 4.08e+01, 1.40e+01, 6.67e+00, 3.31e+00, 1.62e+00, 8.95e-01, 6.50e-01, 5.00e-01, 2.74e-01]
11	792.9	[1.66e+02, 4.48e+01, 1.54e+01, 7.61e+00, 3.85e+00, 2.05e+00, 1.10e+00, 7.15e-01, 5.52e-01, 4.41e-01, 2.33e-01]
12	864.9	[1.73e+02, 4.89e+01, 1.66e+01, 8.63e+00, 4.38e+00, 2.46e+00, 1.35e+00, 8.36e-01, 5.92e-01, 4.82e-01, 3.94e-01, 1.97e-01]
13	937.0	[1.79e+02, 5.17e+01, 1.84e+01, 9.20e+00, 5.15e+00, 2.89e+00, 1.59e+00, 1.00e+00, 6.68e-01, 5.04e-01, 4.33e-01, 3.55e-01, 1.68e-01]
14	1009.1	[1.85e+02, 5.44e+01, 2.00e+01, 9.83e+00, 5.71e+00, 3.49e+00, 1.80e+00, 1.19e+00, 7.81e-01, 5.52e-01, 4.40e-01, 3.96e-01, 3.21e-01, 1.42e-01]
15	1081.2	[1.91e+02, 5.71e+01, 2.16e+01, 1.06e+01, 5.95e+00, 4.28e+00, 2.00e+00, 1.36e+00, 9.16e-01, 6.31e-01, 4.68e-01, 3.93e-01, 3.67e-01, 2.90e-01, 1.21e-01]
16	1153.3	[1.97e+02, 5.94e+01, 2.30e+01, 1.15e+01, 6.59e+00, 4.35e+00, 2.56e+00, 1.51e+00, 1.06e+00, 7.31e-01, 5.23e-01, 4.06e-01, 3.60e-01, 3.43e-01, 2.62e-01,
24	1729.9	[2.35e+02, 7.38e+01, 3.28e+01, 1.78e+01, 1.07e+01, 7.35e+00, 4.97e+00, 3.29e+00, 2.25e+00, 1.64e+00, 1.26e+00, 9.82e-01, 7.64e-01, 5.84e-01, 4.46e-01, 3.47e-01, 2.78e-01, 2.35e-01, 2.25e-01, 2.43e-01, 2.52e-01, 2.04e-01, 1.09e-01, 2.80e-02]
41	3078.1	[2.88e+02, 1.07e+02, 5.30e+01, 3.09e+01, 1.99e+01, 1.39e+01, 1.03e+01, 8.00e+00, 6.64e+00, 5.43e+00, 4.19e+00, 3.18e+00, 2.45e+00, 1.86e+00, 1.43e+00, 1.13e+00, 9.28e-01, 8.00e-01, 7.09e-01, 6.30e-01, 5.50e-01, 4.64e-01, 3.80e-01, 3.05e-01, 2.49e-01, 2.12e-01, 1.87e-01, 1.67e-01, 1.45e-01, 1.24e-01, 1.09e-01, 1.09e-01, 1.27e-01, 1.56e-01, 1.78e-01, 1.75e-01, 1.41e-01, 8.88e-02, 4.08e-02, 1.22e-02, 1.77e-03]

Table E-4. PWR RPS prior, maximum likelihood estimators of α_k .

Group Size	MLE Vector
2	[9.72e-01, 2.76e-02]
3	[9.57e-01, 3.64e-02, 6.36e-03]
4	[9.49e-01, 3.77e-02, 1.08e-02, 2.31e-03]
5	[9.43e-01, 4.01e-02, 1.15e-02, 4.02e-03, 1.38e-03]
6	[9.38e-01, 4.10e-02, 1.35e-02, 4.26e-03, 2.06e-03, 9.39e-04]
7	[9.35e-01, 4.17e-02, 1.41e-02, 5.48e-03, 2.09e-03, 1.29e-03, 6.74e-04]
8	[9.32e-01, 4.20e-02, 1.44e-02, 6.55e-03, 2.35e-03, 1.32e-03, 9.01e-04, 4.99e-04]
9	[9.30e-01, 4.26e-02, 1.46e-02, 6.75e-03, 3.12e-03, 1.40e-03, 9.23e-04, 6.74e-04, 3.77e-04]
10	[9.28e-01, 4.30e-02, 1.47e-02, 7.03e-03, 3.49e-03, 1.71e-03, 9.43e-04, 6.85e-04, 5.27e-04, 2.89e-04]
11	[9.26e-01, 4.33e-02, 1.48e-02, 7.35e-03, 3.72e-03, 1.98e-03, 1.06e-03, 6.90e-04, 5.32e-04, 4.26e-04, 2.25e-04]
12	[9.24e-01, 4.36e-02, 1.48e-02, 7.69e-03, 3.90e-03, 2.19e-03, 1.21e-03, 7.45e-04, 5.27e-04, 4.30e-04, 3.51e-04, 1.76e-04]
13	[9.24e-01, 4.28e-02, 1.52e-02, 7.61e-03, 4.27e-03, 2.39e-03, 1.32e-03, 8.30e-04, 5.53e-04, 4.17e-04, 3.58e-04, 2.94e-04, 1.39e-04]
14	[9.23e-01, 4.21e-02, 1.55e-02, 7.60e-03, 4.41e-03, 2.70e-03, 1.39e-03, 9.16e-04, 6.04e-04, 4.27e-04, 3.40e-04, 3.06e-04, 2.48e-04, 1.10e-04]
15	[9.23e-01, 4.14e-02, 1.57e-02, 7.70e-03, 4.32e-03, 3.10e-03, 1.45e-03, 9.83e-04, 6.65e-04, 4.58e-04, 3.40e-04, 2.85e-04, 2.66e-04, 2.10e-04, 8.78e-05]
16	[9.23e-01, 4.06e-02, 1.57e-02, 7.89e-03, 4.50e-03, 2.97e-03, 1.75e-03, 1.03e-03, 7.22e-04, 5.00e-04, 3.58e-04, 2.77e-04, 2.46e-04, 2.34e-04, 1.79e-04, 7.03e-05]
24	[9.24e-01, 3.47e-02, 1.54e-02, 8.35e-03, 5.05e-03, 3.46e-03, 2.34e-03, 1.55e-03, 1.06e-03, 7.71e-04, 5.92e-04, 4.62e-04, 3.59e-04, 2.75e-04, 2.10e-04, 1.63e-04, 1.31e-04, 1.11e-04, 1.06e-04, 1.15e-04, 1.18e-04, 9.62e-05, 5.13e-05, 1.32e-05]
41	[9.24e-01, 2.93e-02, 1.46e-02, 8.50e-03, 5.46e-03, 3.83e-03, 2.82e-03, 2.20e-03, 1.82e-03, 1.49e-03, 1.15e-03, 8.73e-04, 6.73e-04, 5.12e-04, 3.92e-04, 3.09e-04, 2.55e-04, 2.20e-04, 1.95e-04, 1.73e-04, 1.51e-04, 1.27e-04, 1.04e-04, 8.39e-05, 6.84e-05, 5.81e-05, 5.13e-05, 4.58e-05, 3.99e-05, 3.40e-05, 2.98e-05, 2.98e-05, 3.49e-05, 4.28e-05, 4.90e-05, 4.82e-05, 3.88e-05, 2.44e-05, 1.12e-05, 3.34e-06, 4.85e-07]

E-3.2.4 Uncertainty Distribution

To characterize the uncertainty in the common-cause alpha factors for the RPS, a distribution was associated with each alpha factor in the equation used to estimate each CCF basic event probability (Table E-1). To complete the uncertainty analysis, distributions were needed for the alpha factors, $\alpha^{(m)}_1 \dots \alpha^{(m)}_m$.

In accordance with the methods explained in Section A-2.1.2.1, the prior distributions of the $\alpha^{(m)}_k$ are assumed to be beta distributions. When $\alpha^{(m)}_k$ has a beta prior distribution for the probability of an occurrence, and occurrence data are generated from a binomial distribution with this probability, the posterior distribution from a Bayesian update is also a beta distribution. Thus, beta distributions are conjugate prior distributions for binomial data, and are a natural choice for the uncertainty in the CCF alpha factors.

E-3.2.4.1 Uncertainty in the Prior Alpha Factors. The particular beta distribution for each alpha factor remains to be determined. With the means based on MLE estimates from the data, just a single beta distribution parameter remains to be determined for each $\alpha^{(m)}_k$. Beta distributions are typically characterized by two parameters, α and β . The mean is $\alpha/(\alpha + \beta)$. In the remaining subsections, we focus on estimating the parameter $\delta \equiv \alpha + \beta$, for each $\alpha^{(m)}_k$. As δ increases, the variance of the uncertainty distribution decreases. The following three-step approach was used to estimate the prior distribution δ parameters.

E-3.2.4.2 Constrained Noninformative Distributions for CCF Factors. The first step was to fit a constrained noninformative (CN) prior distribution for each $\alpha^{(m)}_k$, for $k = 2, \dots, m$. In this step, the variance of the selected beta distribution maximizes the entropy, subject to the constraint that the mean matches the estimated probability of loss of k of m components by common-cause. In practice, knowledge of the constrained mean leads to an estimate of the alpha parameter of the desired beta distribution. Figure E-4 shows the relationship between the fixed mean and the alpha parameter of the beta distribution about the mean.

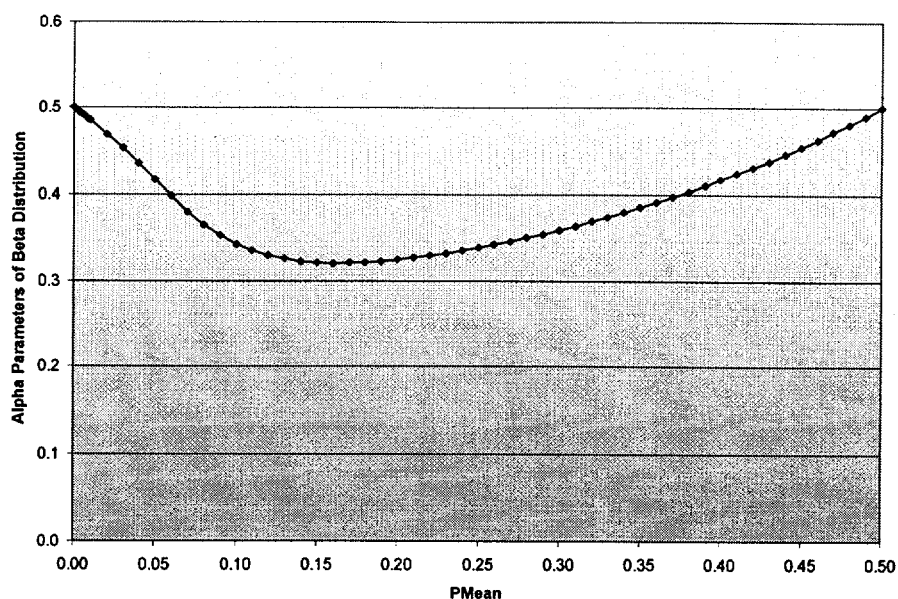


Figure E-4. Constrained non-informative prior alpha calculation.

When the fixed mean is very small (i.e., less than 0.001), the alpha parameter of the fitted CN distribution is approximately 0.50. Given an α parameter, $\delta = \alpha/\text{mean}$. Further details of the method are found in the "Alternate Method" subsection of Section A-2.1.2.1.

The application of the CN distribution assumes that the $\alpha_k^{(m)}$ are statistically independent. It results in a different δ parameter for each CCF $\alpha_k^{(m)}$. However, the sum of the $\alpha_k^{(m)}$ from 1 to m equals 1.0, and they are not statistically independent.

E-3.2.4.3 Dirichlet Distributions for CCF Factors. In this step of the procedure to estimate the prior distributions, we use the Dirichlet distribution. The Dirichlet distribution provides a convenient framework that reflects the dependence and uses a common δ value. The Dirichlet distribution is a multinomial counterpart to a beta distribution function. The marginal distribution for each parameter is a beta distribution. Equation E-12 shows the Dirichlet density function:

$$\pi(x_1, \dots, x_m) = \frac{\Gamma(A_1 + A_2 + \dots + A_m)}{\Gamma(A_1) \dots \Gamma(A_m)} x_1^{A_1-1} x_2^{A_2-1} \dots x_m^{A_m-1} \quad \text{E-12}$$

In this equation, the $x_1, \dots, x_m$ act like multinomial distribution probabilities and are required to sum to 1 (for example, if $m = 2$ then x_1 could be the probability of an event occurring and x_2 would be the probability of it not occurring). The A_k 's [$k = 1, \dots, m$] are the parameters of the distribution and act like the count of events in each of the m categories of the multinomial distribution.

When Equation E-12 is applied to the CCF data, the $\{\alpha_k^{(m)}\}$, for $k = 1, \dots, m$ are substituted for the x_k . The set of alpha parameters $\{\alpha_k^{(m)}\}$ is taken to have a joint Dirichlet distribution. In this case, for any single $\alpha_k^{(m)}$, the marginal distribution is a beta distribution with parameters $\alpha_k = A_k$ and $\beta_k =$ the sum of the remaining A_i , $i = 1, \dots, m$, with i not equal to k . As above, $\delta_k \equiv (\alpha_k + \beta_k)$. Thus, the δ is constant for each of the $\alpha_k^{(m)}$ with the Dirichlet distribution since in each case $\delta_k = \delta = \sum A_k$.

The mean of each common-cause $\alpha_k^{(m)}$ factor is α_k/δ . Given the mean values and δ , the parameters of the uncertainty distributions are thus determined. As above, the smaller the value of δ , the greater the uncertainty.

E-3.2.4.4 Calculation of a Common Delta Parameter. A reasonable choice for the common value of δ is the geometric mean of the δ_k parameters computed in step one. If the magnitudes between the estimated CCF alphas are not large, the geometric mean will result in uncertainty distributions that are not too skewed. Since the prior common-cause mean is α_k/δ , the beta distribution alpha parameter α_k is the mean times δ . From Figure E-4, low mean values lead to CN α_k parameters around 0.5. Since the chosen δ was calculated from the CN δ 's, the resulting α_k parameters will center about 0.5, which is generally not too small. Small values for the alpha parameter of a beta distribution must be avoided, since they result in extremely skewed distributions. The results of the calculation of the δ for the prior distribution are shown in Table E-5.

E-3.2.5 Updating the Prior Distributions with the Data

The resulting prior distributions can now be estimated with the specific RPS CCF data. The mean of the posterior uncertainty distribution (E-13) that results from updating a beta prior distribution with the observed data is a weighted average of the mean of the prior distribution and the maximum likelihood estimate (f_k/d) from the data, as follows:

$$\alpha_k^{(m)} \text{ Post} = \alpha_k^{(m)} \text{ Prior} * \frac{\delta}{\delta + d} + \frac{f_k}{d} * \frac{d}{d + \delta} \quad \text{E-13}$$

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where:

$\alpha_{k Post}^{(m)}$	=	posterior alpha factor for exactly k failures among m components in one event
$\alpha_{k Prior}^{(m)}$	=	prior alpha factor for exactly k failures among m components in one event
δ	$\equiv$	the prior distribution common delta parameter
f_k	=	the sum of the k^{th} impact vector elements for the component, CCCG (m), and degree of CCF loss (k) under consideration
d	=	the sum of all the impact vector elements for the CCCG (m) and component under consideration

E-3.2.6 Data Selection

Component failure data were selected from the RPS CCF database to match the criteria of each defined CCF basic event used in the fault trees. Data for the component of interest included events in which the Safety Function is either NFS or UKN. The associated component independent failure count was extracted from the database as outlined in Appendix C. In those cases where the independent failure data were pooled across selected PWR vendors, the CCF data were pooled using the same vendor criteria.

E-3.3 CCF Basic Event Probability Results

E-3.3.1 Bayesian Update Results

Table E-6 shows the results of the CCF BE calculations updated with the beta prior for those components modeled in the fault trees. The Failure Criterion designation for each component points to an equation in Table E-1.

Table E-7 shows the lognormal uncertainty parameters for the CCF BEs. Error propagation using the equations in Table E-1, the beta distributions described in Section E-3.2.4.1, and the lognormal uncertainty distribution for Q_T leads to uncertainty distributions on the estimated BE probabilities. The process, leading to lognormal distributions, is explained in Section A-2.2.

E-3.3.2 Classical Results

The classical or no prior influence results are of no interest for Babcock & Wilcox. With zero CCF data for most of the components, all classical results are $\ll 1.0E-10$.

Table E-5. RPS prior, constrained noninformative δ and the average of δ .

Group Size	Delta Vector	Delta Average	Delta Geometric Mean
2	[1.69e+01, 1.69e+01]	16.9	16.9
3	[9.89e+00, 1.23e+01, 7.71e+01]	33.1	21.1
4	[7.87e+00, 1.19e+01, 4.36e+01, 2.15e+02]	69.6	30.6
5	[7.21e+00, 1.04e+01, 4.09e+01, 1.22e+02, 3.60e+02]	108.3	42.3
6	[6.21e+00, 1.02e+01, 3.51e+01, 1.16e+02, 2.41e+02, 5.32e+02]	156.7	56.7
7	[5.97e+00, 1.01e+01, 3.38e+01, 8.97e+01, 2.37e+02, 3.85e+02, 7.41e+02]	214.6	74.2
8	[5.80e+00, 1.00e+01, 3.30e+01, 7.48e+01, 2.11e+02, 3.76e+02, 5.55e+02, 1.00e+03]	283.3	94.4
9	[5.19e+00, 9.91e+00, 3.27e+01, 7.26e+01, 1.59e+02, 3.57e+02, 5.41e+02, 7.41e+02, 1.32e+03]	360.2	115.6
10	[5.09e+00, 9.84e+00, 3.24e+01, 6.94e+01, 1.42e+02, 2.92e+02, 5.30e+02, 7.29e+02, 9.47e+02, 1.72e+03]	448.1	140.2
11	[5.01e+00, 9.78e+00, 3.21e+01, 6.65e+01, 1.33e+02, 2.52e+02, 4.67e+02, 7.24e+02, 9.38e+02, 1.17e+03, 2.22e+03]	547.4	167.4
12	[4.94e+00, 9.73e+00, 3.21e+01, 6.36e+01, 1.27e+02, 2.26e+02, 4.12e+02, 6.71e+02, 9.47e+02, 1.16e+03, 1.42e+03, 2.84e+03]	659.3	197.2
13	[4.92e+00, 9.87e+00, 3.14e+01, 6.42e+01, 1.16e+02, 2.07e+02, 3.77e+02, 6.02e+02, 9.03e+02, 1.20e+03, 1.39e+03, 1.70e+03,	784.6	229.5
14	[4.89e+00, 1.00e+01, 3.09e+01, 6.43e+01, 1.12e+02, 1.84e+02, 3.57e+02, 5.46e+02, 8.27e+02, 1.17e+03, 1.47e+03, 1.63e+03, 2.01e+03, 4.53e+03]	924.8	264.5
15	[4.88e+00, 1.01e+01, 3.05e+01, 6.35e+01, 1.14e+02, 1.59e+02, 3.43e+02, 5.08e+02, 7.51e+02, 1.09e+03, 1.47e+03, 1.75e+03, 1.88e+03, 2.37e+03, 5.68e+03]	1081.4	302.3
16	[4.87e+00, 1.03e+01, 3.04e+01, 6.20e+01, 1.10e+02, 1.67e+02, 2.85e+02, 4.82e+02, 6.92e+02, 9.99e+02, 1.39e+03, 1.80e+03, 2.03e+03, 2.13e+03, 2.78e+03, 7.09e+03]	1254.4	342.1
24	[4.94e+00, 1.28e+01, 3.10e+01, 5.83e+01, 9.71e+01, 1.43e+02, 2.12e+02, 3.22e+02, 4.70e+02, 6.48e+02, 8.43e+02, 1.08e+03, 1.39e+03, 1.81e+03, 2.38e+03, 3.06e+03, 3.82e+03, 4.51e+03, 4.71e+03, 4.35e+03, 4.21e+03, 5.18e+03, 9.72e+03, 3.78e+04]	3621.3	763.9
41	[4.93e+00, 1.60e+01, 3.27e+01, 5.73e+01, 9.00e+01, 1.29e+02, 1.76e+02, 2.26e+02, 2.73e+02, 3.34e+02, 4.32e+02, 5.72e+02, 7.43e+02, 9.75e+02, 1.27e+03, 1.61e+03, 1.96e+03, 2.27e+03, 2.56e+03, 2.88e+03, 3.30e+03, 3.91e+03, 4.78e+03, 5.95e+03, 7.29e+03, 8.58e+03, 9.72e+03, 1.09e+04, 1.25e+04, 1.47e+04, 1.67e+04, 1.67e+04, 1.43e+04, 1.16e+04, 1.02e+04, 1.04e+04, 1.29e+04, 2.04e+04, 4.45e+04, 1.49e+05, 1.00e+06]	34271.3	2252.4

Table E-6. Bayesian update CCF basic event results.

Basic Event Name	Failure Criterion	QT Mean	CCF Basic Event Failure Probability	Updated Alpha Vector	Event Description
B&W Davis-Besse					
BWD-BME-CF-TB2OF4	2/4	1.80E-05	7.07E-07	[9.52e-01, 3.54e-02, 1.01e-02, 2.17e-03]	CCF Specific 2 of 4 Trip Breakers One out of Two Twice
BWD-BSN-CF-TB2OF4	2/4	6.10E-04	2.32E-05	[9.54e-01, 3.43e-02, 9.82e-03, 2.10e-03]	CCF Specific 2 of 4 Trip Breaker Shunt Trip Devices
BWD-BUV-CF-TB2OF4	2/4	2.30E-04	7.52E-06	[9.60e-01, 2.95e-02, 8.44e-03, 1.81e-03]	CCF Specific 2 of 4 Trip Breaker Undervoltage Trip Devices
BWD-CBI-CF-CBI4OF6TM	4/6 8	2.90E-04	8.70E-07	[9.46e-01, 3.35e-02, 1.13e-02, 5.07e-03, 1.80e-03, 1.02e-03, 6.92e-04, 3.83e-04]	CCF Specific 4 of 6 Bistables CH-A TM
BWD-CBI-CF-CBI6OF8	6/8	2.90E-04	3.97E-07	[9.46e-01, 3.35e-02, 1.13e-02, 5.07e-03, 1.80e-03, 1.02e-03, 6.92e-04, 3.83e-04]	CCF Specific 6 of 8 Bistables
BWD-CPR-CF-P2OF3TM	2/3 4	1.60E-04	6.38E-06	[9.63e-01, 2.71e-02, 9.15e-03, 5.75e-04]	CCF 2 of 3 Pressure Sensors/Transmitters CH-A TM
BWD-CPR-CF-P3OF4	3/4	1.60E-04	2.05E-06	[9.63e-01, 2.71e-02, 9.15e-03, 5.75e-04]	CCF 3 of 4 Pressure Sensors/Transmitters
BWD-CTP-CF-T2OF3TM	2/3 4	1.20E-04	4.95E-06	[9.61e-01, 2.86e-02, 8.19e-03, 1.75e-03]	CCF 2 of 3 Temperature Sensors/Transmitters CH-A TM
BWD-CTP-CF-T3OF4	3/4	1.20E-04	1.52E-06	[9.61e-01, 2.86e-02, 8.19e-03, 1.75e-03]	CCF 3 of 4 Temperature Sensors/Transmitters
BWD-MSW-CF-2OF4	2/4	1.30E-04	5.43E-06	[9.49e-01, 3.77e-02, 1.08e-02, 2.31e-03]	CCF Specific 2 of 4 Manual Trip Switches
BWD-PWR-CF-TB2OF4	2/4	6.00E-05	2.51E-06	[9.49e-01, 3.77e-02, 1.08e-02, 2.31e-03]	CCF Specific 2 of 4 Shunt Trip Power Supplies
BWD-ROD-CF-RODS	8/41	2.00E-05	8.40E-07	[9.24e-01, 2.93e-02, 1.46e-02, 8.50e-03, 5.46e-03, 3.83e-03, 2.82e-03, 2.20e-03, 1.82e-03, 1.49e-03, 1.15e-03, 8.73e-04, 6.72e-04, 5.12e-04, 3.92e-04, 3.09e-04, 2.55e-04, 2.20e-04, 1.95e-04, 1.73e-04, 1.51e-04, 1.27e-04, 1.04e-04, 8.38e-05, 6.84e-05, 5.81e-05, 4.58e-05, 3.99e-05, 3.40e-05, 2.98e-05, 2.98e-05, 3.49e-05, 4.28e-05, 4.90e-05, 4.82e-05, 3.88e-05, 2.44e-05, 1.12e-05, 3.34e-06, 4.85e-07]	CCF 20 percent CRD/RODS Fail to Insert

Table E-6. Bayesian update CCF basic event results. (Continued)

Basic Event Name	Failure Criterion	QT Mean	CCF Basic Event Failure Probability	Updated Alpha Vector	Event Description
BWD-RYL-CF-LR2OF6TM	2/6 8	2.10E-05	2.51E-06	[9.33e-01, 4.11e-02, 1.41e-02, 6.41e-03, 2.30e-03, 1.30e-03, 8.83e-04, 4.88e-04]	CCF Specific 2 of 6 Logic Relays. Channels C and D only for the electronic trip. CH-A TM
BWD-RYL-CF-LR3OF8	3/8	2.10E-05	8.43E-07	[9.33e-01, 4.11e-02, 1.41e-02, 6.41e-03, 2.30e-03, 1.30e-03, 8.83e-04, 4.88e-04]	CCF Specific 3 of 8 Logic Relays. Channels C and D only for the electronic trip.
BWD-RYL-CF-LR6OF12TM	6/12 16	2.10E-05	5.85E-08	[9.23e-01, 4.04e-02, 1.56e-02, 7.84e-03, 4.48e-03, 2.96e-03, 1.74e-03, 1.03e-03, 7.17e-04, 4.97e-04, 3.56e-04, 2.76e-04, 2.44e-04, 2.33e-04, 1.78e-04, 6.99e-05]	CCF Specific 6 of 12 Logic Relays CH-A TM
BWD-RYL-CF-LR9OF16	9/16	2.10E-05	3.32E-08	[9.23e-01, 4.04e-02, 1.56e-02, 7.84e-03, 4.48e-03, 2.96e-03, 1.74e-03, 1.03e-03, 7.17e-04, 4.97e-04, 3.56e-04, 2.76e-04, 2.44e-04, 2.33e-04, 1.78e-04, 6.99e-05]	CCF Specific 9 of 16 Logic Relays
BWD-RYL-CF-TR2OF3TM	2/3 4	2.10E-05	1.07E-06	[9.52e-01, 3.53e-02, 1.01e-02, 2.17e-03]	CCF 2 of 3 Trip Relays CH-A TM
BWD-RYL-CF-TR3OF4	3/4	2.10E-05	3.29E-07	[9.52e-01, 3.53e-02, 1.01e-02, 2.17e-03]	CCF 3 of 4 Trip Relays
B&W Ocone					
BWO-BME-CF-TB3OF6-4G	2/6 U	1.80E-05	1.05E-06	[9.41e-01, 3.90e-02, 1.28e-02, 4.04e-03, 1.95e-03, 8.92e-04]	CCF 2 or More of 6 Trip Breakers That Fail Two or More Groups
BWO-BSN-CF-TB3OF6-4G	2/6 U	6.10E-04	3.54E-05	[9.41e-01, 3.89e-02, 1.28e-02, 4.04e-03, 1.95e-03, 8.92e-04]	CCF 2 or More of 6 Trip Breaker Shunt Trip Devices That Fail Two or More Groups
BWO-BUV-CF-TB3OF6-4G	2/6 U	2.30E-04	1.22E-05	[9.46e-01, 3.56e-02, 1.18e-02, 3.70e-03, 1.79e-03, 8.17e-04]	CCF 2 or More of 6 Trip Breaker Undervoltage Trip Devices That Fail Two or More Groups
BWO-CBI-CF-CBI4OF6TM	4/6 8	2.90E-04	8.70E-07	[9.46e-01, 3.35e-02, 1.13e-02, 5.07e-03, 1.80e-03, 1.02e-03, 6.92e-04, 3.83e-04]	CCF Specific 4 of 6 Bistables CH-A TM
BWO-CBI-CF-CBI6OF8	6/8	2.90E-04	3.97E-07	[9.46e-01, 3.35e-02, 1.13e-02, 5.07e-03, 1.80e-03, 1.02e-03, 6.92e-04, 3.83e-04]	CCF Specific 6 of 8 Bistables
BWO-CPR-CF-P2OF3TM	2/3 4	1.60E-04	6.38E-06	[9.63e-01, 2.71e-02, 9.15e-03, 5.75e-04]	CCF 2 of 3 Pressure Sensors/Transmitters CH-A TM

Table E-6. Bayesian update CCF basic event results. (Continued)

Basic Event Name	Failure Criterion	QT Mean	CCF Basic Event Failure Probability	Updated Alpha Vector	Event Description
BWO-CPR-CF-P3OF4	3/4	1.60E-04	2.05E-06	[9.63e-01, 2.71e-02, 9.15e-03, 5.75e-04]	CCF 3 of 4 Pressure Sensors/Transmitters
BWO-CTP-CF-T2OF3TM	2/3 4	1.20E-04	4.95E-06	[9.61e-01, 2.86e-02, 8.19e-03, 1.75e-03]	CCF 2 of 3 Temperature Sensors/Transmitters CH-A TM
BWO-CTP-CF-T3OF4	3/4	1.20E-04	1.52E-06	[9.61e-01, 2.86e-02, 8.19e-03, 1.75e-03]	CCF 3 of 4 Temperature Sensors/Transmitters
BWO-MSW-CF-2OF4	2/4	1.30E-04	5.43E-06	[9.49e-01, 3.77e-02, 1.08e-02, 2.31e-03]	CCF Specific 2 of 4 Manual Trip Switches
BWO-PWR-CF-TB2OF4	2/4	6.00E-05	2.51E-06	[9.49e-01, 3.77e-02, 1.08e-02, 2.31e-03]	CCF Specific 2 of 4 Shunt Trip Power Supplies
BWO-ROD-CF-RODS	8/41	2.00E-05	8.40E-07	[9.24e-01, 2.93e-02, 1.46e-02, 8.50e-03, 5.46e-03, 3.83e-03, 2.82e-03, 2.20e-03, 1.82e-03, 1.49e-03, 1.15e-03, 8.73e-04, 6.72e-04, 5.12e-04, 3.92e-04, 3.09e-04, 2.55e-04, 2.20e-04, 1.95e-04, 1.73e-04, 1.51e-04, 1.27e-04, 1.04e-04, 8.38e-05, 6.84e-05, 5.81e-05, 4.58e-05, 3.99e-05, 3.40e-05, 2.98e-05, 2.98e-05, 3.49e-05, 4.28e-05, 4.90e-05, 4.82e-05, 3.88e-05, 2.44e-05, 1.12e-05, 3.34e-06, 4.85e-07]	CCF 20 Percent CRD/RODS Fail to Insert
BWO-RYL-CF-LR2OF6TM	2/6 8	2.10E-05	2.51E-06	[9.33e-01, 4.11e-02, 1.41e-02, 6.41e-03, 2.30e-03, 1.30e-03, 8.83e-04, 4.88e-04]	CCF Specific 2 of 6 Logic Relays. Channels C and D only for the electronic trip. CH-A TM
BWO-RYL-CF-LR3OF8	3/8	2.10E-05	8.43E-07	[9.33e-01, 4.11e-02, 1.41e-02, 6.41e-03, 2.30e-03, 1.30e-03, 8.83e-04, 4.88e-04]	CCF Specific 3 of 8 Logic Relays. Channels C and D only for the electronic trip.
BWO-RYL-CF-LR6OF12TM	6/12 16	2.10E-05	5.85E-08	[9.23e-01, 4.04e-02, 1.56e-02, 7.84e-03, 4.48e-03, 2.96e-03, 1.74e-03, 1.03e-03, 7.17e-04, 4.97e-04, 3.56e-04, 2.76e-04, 2.44e-04, 2.33e-04, 1.78e-04, 6.99e-05]	CCF Specific 6 of 12 Logic Relays CH-A TM
BWO-RYL-CF-LR9OF16	9/16	2.10E-05	3.32E-08	[9.23e-01, 4.04e-02, 1.56e-02, 7.84e-03, 4.48e-03, 2.96e-03, 1.74e-03, 1.03e-03, 7.17e-04, 4.97e-04, 3.56e-04, 2.76e-04, 2.44e-04, 2.33e-04, 1.78e-04, 6.99e-05]	CCF Specific 9 of 16 Logic Relays
BWO-RYL-CF-TR2OF3TM	2/3 4	2.10E-05	1.07E-06	[9.52e-01, 3.53e-02, 1.01e-02, 2.17e-03]	CCF 2 of 3 Trip Relays CH-A TM
BWO-RYL-CF-TR3OF4	3/4	2.10E-05	3.29E-07	[9.52e-01, 3.53e-02, 1.01e-02, 2.17e-03]	CCF 3 of 4 Trip Relays

Table E-6. Bayesian update CCF basic event results. (Continued)

Basic Event Name	Failure Criterion	QT Mean	CCF Basic Event Failure Probability	Updated Alpha Vector	Event Description
Sensitivity					
BW-CBI-CF-6OF9TM	6/9 12	2.90E-04	2.51E-07	[9.37e-01, 3.73e-02, 1.25e-02, 6.28e-03, 3.05e-03, 1.62e-03, 8.67e-04, 5.31e-04, 3.76e-04, 3.06e-04, 2.50e-04, 1.25e-04]	CCF Specific 6 of 9 Bistables for Three Parameter Sensitivity Channel A in Test
BW-CBI-CF-9OF12	9/12	2.90E-04	1.38E-07	[9.37e-01, 3.73e-02, 1.25e-02, 6.28e-03, 3.05e-03, 1.62e-03, 8.67e-04, 5.31e-04, 3.76e-04, 3.06e-04, 2.50e-04, 1.25e-04]	CCF Specific 9 of 12 Bistables for Three Parameter Sensitivity

Appendix E

Table E-7. Lognormal uncertainty distributions for CCF events.

Basic Event Name	Median	EF	CCF Failure Probability Low	CCF Mean Failure Probability	CCF Failure Probability Upper
BW-CBI-CF-6OF9TM	1.13E-07	8.01	1.41E-08	2.51E-07	9.02E-07
BW-CBI-CF-9OF12	4.40E-08	11.98	3.67E-09	1.38E-07	5.27E-07
BWD-BME-CF-TB2OF4	4.24E-07	5.28	8.03E-08	7.07E-07	2.24E-06
BWD-BSN-CF-TB2OF4	1.58E-05	4.22	3.75E-06	2.32E-05	6.68E-05
BWD-BUV-CF-TB2OF4	5.37E-06	3.85	1.39E-06	7.52E-06	2.07E-05
BWD-CBI-CF-CBI4OF6TM	4.63E-07	6.36	7.28E-08	8.70E-07	2.94E-06
BWD-CBI-CF-CBI6OF8	1.39E-07	10.85	1.28E-08	3.97E-07	1.51E-06
BWD-CPR-CF-P2OF3TM	5.81E-06	2.05	2.84E-06	6.38E-06	1.19E-05
BWD-CPR-CF-P3OF4	1.53E-06	3.50	4.37E-07	2.05E-06	5.36E-06
BWD-CTP-CF-T2OF3TM	1.79E-06	10.44	1.72E-07	4.95E-06	1.87E-05
BWD-CTP-CF-T3OF4	3.78E-07	15.56	2.43E-08	1.52E-06	5.88E-06
BWD-MSW-CF-2OF4	3.30E-06	5.16	6.41E-07	5.43E-06	1.70E-05
BWD-PWR-CF-TB2OF4	1.37E-06	6.07	2.27E-07	2.51E-06	8.34E-06
BWD-ROD-CF-RODS	2.80E-07	11.46	2.44E-08	8.40E-07	3.21E-06
BWD-RYL-CF-LR2OF6TM	1.97E-06	3.14	6.28E-07	2.51E-06	6.17E-06
BWD-RYL-CF-LR3OF8	6.00E-07	3.89	1.54E-07	8.43E-07	2.33E-06
BWD-RYL-CF-LR6OF12TM	3.57E-08	5.13	6.96E-09	5.85E-08	1.83E-07
BWD-RYL-CF-LR9OF16	1.66E-08	6.92	2.40E-09	3.32E-08	1.15E-07
BWD-RYL-CF-TR2OF3TM	7.10E-07	4.45	1.60E-07	1.07E-06	3.16E-06
BWD-RYL-CF-TR3OF4	1.50E-07	7.86	1.91E-08	3.29E-07	1.18E-06
BWO-BME-CF-TB3OF6-4G	7.14E-07	4.21	1.69E-07	1.05E-06	3.01E-06
BWO-BSN-CF-TB3OF6-4G	2.75E-05	3.22	8.52E-06	3.54E-05	8.85E-05
BWO-BUV-CF-TB3OF6-4G	9.95E-06	2.87	3.46E-06	1.22E-05	2.86E-05
BWO-CBI-CF-CBI4OF6TM	4.63E-07	6.36	7.28E-08	8.70E-07	2.94E-06
BWO-CBI-CF-CBI6OF8	1.39E-07	10.85	1.28E-08	3.97E-07	1.51E-06
BWO-CPR-CF-P2OF3TM	5.81E-06	2.05	2.84E-06	6.38E-06	1.19E-05
BWO-CPR-CF-P3OF4	1.53E-06	3.50	4.37E-07	2.05E-06	5.36E-06
BWO-CTP-CF-T2OF3TM	1.79E-06	10.44	1.72E-07	4.95E-06	1.87E-05
BWO-CTP-CF-T3OF4	3.78E-07	15.56	2.43E-08	1.52E-06	5.88E-06
BWO-MSW-CF-2OF4	3.30E-06	5.16	6.41E-07	5.43E-06	1.70E-05
BWO-PWR-CF-TB2OF4	1.37E-06	6.07	2.27E-07	2.51E-06	8.34E-06
BWO-ROD-CF-RODS	2.80E-07	11.46	2.44E-08	8.40E-07	3.21E-06
BWO-RYL-CF-LR2OF6TM	1.97E-06	3.14	6.28E-07	2.51E-06	6.17E-06
BWO-RYL-CF-LR3OF8	6.00E-07	3.89	1.54E-07	8.43E-07	2.33E-06
BWO-RYL-CF-LR6OF12TM	3.57E-08	5.13	6.96E-09	5.85E-08	1.83E-07
BWO-RYL-CF-LR9OF16	1.66E-08	6.92	2.40E-09	3.32E-08	1.15E-07
BWO-RYL-CF-TR2OF3TM	7.10E-07	4.45	1.60E-07	1.07E-06	3.16E-06
BWO-RYL-CF-TR3OF4	1.50E-07	7.86	1.91E-08	3.29E-07	1.18E-06

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- E-1. F. M. Marshall et. al., *Common-Cause Failure Database and Analysis System: Event Definition and Classification*, NUREG/CR-6268, Vol. 2, June 1998.
- E-2. U.S. NRC, *Guidelines on Modeling Common-Cause Failures in Probabilistic Risk Assessment*, NUREG/CR-5485, Nov. 1998.
- E-3. Kvam, Paul, *Estimation Techniques for Common Cause Failure Data with Different System Sizes*, Technometrics, Volume 38, No. 4, pages 382-388, 1996.

Appendix F

Fault Tree Quantification Results

Appendix F Fault Tree Quantification Results

F. Introduction

This appendix contains the SAPHIRE cut sets, importance rankings, and basic event reports from the quantification of the Babcock & Wilcox RPS fault trees. Two separate cases of results are presented in this appendix for each RPS design group.

The first case of results presented assumes that the basic event value for the operator failing to initiate a scram (BWx-XHE-XE-SCRAM) is TRUE (i.e., failure probability is 1.0). The second case of results presented assumes that the basic event value for the operator failing to initiate a scram (BWx-XHE-XE-SCRAM) is 0.01. The RPS fault tree cut sets were generated with no truncation level specified.

The cut sets contain some basic events with a “/” in front of them. A “/” as the first character in a basic event name indicates a complemented event (Success = 1-Failure). For example, the basic event for reactor low water level trip signal channel A in test and maintenance (T&M) is BWx-RPS-TM-CHA (Failure = 1.6E-2). Thus, the basic event name for channel A not in T&M is /BWx-RPS-TM-CHA (Success = 9.8E-1). The event description for complimented events remains the same as the description used for the failure event.

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Table F-1. RPS B&W Davis-Besse top 50 cutsets (no manual scram).

Cut Set	Cut Set %	Cut Set Prob.	Basic Event ^a	Description	Prob.
1	51.9	8.40E-07	BWD-ROD-CF-RODS	CCF 20% OR MORE CRD/RODS FAIL TO INSERT	8.40E-07
2	24.1	3.90E-07	BWD-CBI-CF-CBI6OF8	CCF SPECIFIC 6 OF 8 OUTPUT BISTABLES	4.00E-07
			/BWD-RPS-TM-CHA	CHANNEL A TEST AND MAINTENANCE	9.80E-01
3	20	3.20E-07	/BWD-RPS-TM-CHA	CHANNEL A TEST AND MAINTENANCE	9.80E-01
			BWD-RYL-CF-TR3OF4	CCF 3 OF 4 TRIP RELAYS	3.30E-07
4	2	3.30E-08	/BWD-RPS-TM-CHA	CHANNEL A TEST AND MAINTENANCE	9.80E-01
			BWD-RYL-CF-LR9OF16	CCF SPECIFIC 9 OF 16 LOGIC RELAYS	3.30E-08
5	1.1	1.70E-08	BWD-RPS-TM-CHA	CHANNEL A TEST AND MAINTENANCE	1.60E-02
			BWD-RYL-CF-TR2OF3TM	CCF 2 OF 3 TRIP RELAYS (CH-A T&M)	1.10E-06
6	0.9	1.40E-08	BWD-CBI-CF-CBI4OF6TM	CCF SPECIFIC 4 OF 6 OUTPUT BISTABLES (CH-A T&M)	8.70E-07
			BWD-RPS-TM-CHA	CHANNEL A TEST AND MAINTENANCE	1.60E-02
7	0.1	9.40E-10	BWD-RPS-TM-CHA	CHANNEL A TEST AND MAINTENANCE	1.60E-02
			BWD-RYL-CF-LR6OF12TM	CCF SPECIFIC 6 OF 12 LOGIC RELAYS (CH-A T&M)	5.80E-08
8	0	1.50E-11	BWD-BME-CF-TB2OF4	CCF 2 OF 4 (1-OUT-OF-2 TWICE) TRIP BREAKERS	7.10E-07
			BWD-RYL-FF-DC10	DIVERSE TRIP RELAY C10 FAILS	2.10E-05
9	0	1.50E-11	BWD-BME-CF-TB2OF4	CCF 2 OF 4 (1-OUT-OF-2 TWICE) TRIP BREAKERS	7.10E-07
			BWD-RYL-FF-DD10	DIVERSE TRIP RELAY D10 FAILS	2.10E-05
10	0	7.10E-12	BWD-RPS-TM-CHA	CHANNEL A TEST AND MAINTENANCE	1.60E-02
			BWD-RYL-FF-TRB	TRIP RELAY B FAILS	2.10E-05
			BWD-RYL-FF-TRC	TRIP RELAY C FAILS	2.10E-05
11	0	7.10E-12	BWD-RPS-TM-CHA	CHANNEL A TEST AND MAINTENANCE	1.60E-02
			BWD-RYL-FF-TRB	TRIP RELAY B FAILS	2.10E-05
			BWD-RYL-FF-TRD	TRIP RELAY D FAILS	2.10E-05
12	0	7.10E-12	BWD-RPS-TM-CHA	CHANNEL A TEST AND MAINTENANCE	1.60E-02
			BWD-RYL-FF-TRC	TRIP RELAY C FAILS	2.10E-05
			BWD-RYL-FF-TRD	TRIP RELAY D FAILS	2.10E-05
13	0	3.10E-12	BWD-CPR-CF-P3OF4	CCF 3 OF 4 PRESSURE SENSORS/TRANSMITTERS	2.00E-06
			BWD-CTP-CF-T3OF4	CCF 3 OF 4 TEMPERATURE SENSORS/TRANSMITTERS	1.50E-06
			/BWD-RPS-TM-CHA	CHANNEL A TEST AND MAINTENANCE	9.80E-01
14	0	5.90E-13	BWD-BME-CF-TB2OF4	CCF 2 OF 4 (1-OUT-OF-2 TWICE) TRIP BREAKERS	7.10E-07
			/BWD-RPS-TM-CHA	CHANNEL A TEST AND MAINTENANCE	9.80E-01
			BWD-RYL-CF-LR3OF8	CCF 3 OF 8 LOGIC RELAYS. CHANNELS C & D ONLY FOR ELEC TRIP	8.40E-07
15	0	5.10E-13	BWD-CPR-CF-P2OF3TM	CCF 2 OF 3 PRESSURE SENSORS/TRANSMITTERS (CH-A T&M)	6.40E-06
			BWD-CTP-CF-T2OF3TM	CCF 2 OF 3 TEMPERATURE SENSORS/TRANSMITTERS (CH-A T&M)	4.90E-06
			BWD-RPS-TM-CHA	CHANNEL A TEST AND MAINTENANCE	1.60E-02
16	0	2.80E-14	BWD-BME-CF-TB2OF4	CCF 2 OF 4 (1-OUT-OF-2 TWICE) TRIP BREAKERS	7.10E-07
			BWD-RPS-TM-CHA	CHANNEL A TEST AND MAINTENANCE	1.60E-02
			BWD-RYL-CF-LR2OF6TM	CCF 2 OF 6 LOGIC RYLS. CH C&D FOR THE ELEC TRIP (CH-A T&M)	2.50E-06
17	0	2.80E-14	BWD-CBI-FF-PB	CH-B PRESSURE OUTPUT BISTABLE FAILS	2.90E-04
			BWD-CBI-FF-TB	CH-B TEMPERATURE OUTPUT BISTABLE FAILS	2.90E-04
			BWD-RPS-TM-CHA	CHANNEL A TEST AND MAINTENANCE	1.60E-02
			BWD-RYL-FF-TRC	TRIP RELAY C FAILS	2.10E-05
18	0	2.80E-14	BWD-CBI-FF-PB	CH-B PRESSURE OUTPUT BISTABLE FAILS	2.90E-04
			BWD-CBI-FF-TB	CH-B TEMPERATURE OUTPUT BISTABLE FAILS	2.90E-04
			BWD-RPS-TM-CHA	CHANNEL A TEST AND MAINTENANCE	1.60E-02
			BWD-RYL-FF-TRD	TRIP RELAY D FAILS	2.10E-05
19	0	2.80E-14	BWD-CBI-FF-PC	CH-C PRESSURE OUTPUT BISTABLE FAILS	2.90E-04
			BWD-CBI-FF-TC	CH-C TEMPERATURE OUTPUT BISTABLE FAILS	2.90E-04
			BWD-RPS-TM-CHA	CHANNEL A TEST AND MAINTENANCE	1.60E-02
			BWD-RYL-FF-TRB	TRIP RELAY B FAILS	2.10E-05
20	0	2.80E-14	BWD-CBI-FF-PC	CH-C PRESSURE OUTPUT BISTABLE FAILS	2.90E-04
			BWD-CBI-FF-TC	CH-C TEMPERATURE OUTPUT BISTABLE FAILS	2.90E-04
			BWD-RPS-TM-CHA	CHANNEL A TEST AND MAINTENANCE	1.60E-02
			BWD-RYL-FF-TRD	TRIP RELAY D FAILS	2.10E-05
21	0	2.80E-14	BWD-CBI-FF-PD	CH-D PRESSURE OUTPUT BISTABLE FAILS	2.90E-04
			BWD-CBI-FF-TD	CH-D TEMPERATURE OUTPUT BISTABLE FAILS	2.90E-04
			BWD-RPS-TM-CHA	CHANNEL A TEST AND MAINTENANCE	1.60E-02
			BWD-RYL-FF-TRB	TRIP RELAY B FAILS	2.10E-05
22	0	2.80E-14	BWD-CBI-FF-PD	CH-D PRESSURE OUTPUT BISTABLE FAILS	2.90E-04
			BWD-CBI-FF-TD	CH-D TEMPERATURE OUTPUT BISTABLE FAILS	2.90E-04
			BWD-RPS-TM-CHA	CHANNEL A TEST AND MAINTENANCE	1.60E-02
			BWD-RYL-FF-TRC	TRIP RELAY C FAILS	2.10E-05

Appendix F

Table F-1. (Continued)

Cut Set	Cut Set %	Cut Set Prob.	Basic Event ^a	Description	Prob.
23	0	1.60E-14	BWD-CBI-FF-TB	CH-B TEMPERATURE OUTPUT BISTABLE FAILS	2.90E-04
			BWD-CPR-FF-PB	CH-B PRESSURE SENSOR/TRANSMITTER FAILS	1.60E-04
			BWD-RPS-TM-CHA	CHANNEL A TEST AND MAINTENANCE	1.60E-02
			BWD-RYL-FF-TRC	TRIP RELAY C FAILS	2.10E-05
24	0	1.60E-14	BWD-CBI-FF-TB	CH-B TEMPERATURE OUTPUT BISTABLE FAILS	2.90E-04
			BWD-CPR-FF-PB	CH-B PRESSURE SENSOR/TRANSMITTER FAILS	1.60E-04
			BWD-RPS-TM-CHA	CHANNEL A TEST AND MAINTENANCE	1.60E-02
			BWD-RYL-FF-TRD	TRIP RELAY D FAILS	2.10E-05
25	0	1.60E-14	BWD-CBI-FF-TC	CH-C TEMPERATURE OUTPUT BISTABLE FAILS	2.90E-04
			BWD-CPR-FF-PC	CH-C PRESSURE SENSOR/TRANSMITTER FAILS	1.60E-04
			BWD-RPS-TM-CHA	CHANNEL A TEST AND MAINTENANCE	1.60E-02
			BWD-RYL-FF-TRB	TRIP RELAY B FAILS	2.10E-05
26	0	1.60E-14	BWD-CBI-FF-TC	CH-C TEMPERATURE OUTPUT BISTABLE FAILS	2.90E-04
			BWD-CPR-FF-PC	CH-C PRESSURE SENSOR/TRANSMITTER FAILS	1.60E-04
			BWD-RPS-TM-CHA	CHANNEL A TEST AND MAINTENANCE	1.60E-02
			BWD-RYL-FF-TRD	TRIP RELAY D FAILS	2.10E-05
27	0	1.60E-14	BWD-CBI-FF-TD	CH-D TEMPERATURE OUTPUT BISTABLE FAILS	2.90E-04
			BWD-CPR-FF-PD	CH-D PRESSURE SENSOR/TRANSMITTER FAILS	1.60E-04
			BWD-RPS-TM-CHA	CHANNEL A TEST AND MAINTENANCE	1.60E-02
			BWD-RYL-FF-TRB	TRIP RELAY B FAILS	2.10E-05
28	0	1.60E-14	BWD-CBI-FF-TD	CH-D TEMPERATURE OUTPUT BISTABLE FAILS	2.90E-04
			BWD-CPR-FF-PD	CH-D PRESSURE SENSOR/TRANSMITTER FAILS	1.60E-04
			BWD-RPS-TM-CHA	CHANNEL A TEST AND MAINTENANCE	1.60E-02
			BWD-RYL-FF-TRC	TRIP RELAY C FAILS	2.10E-05
29	0	1.20E-14	BWD-CBI-FF-PB	CH-B PRESSURE OUTPUT BISTABLE FAILS	2.90E-04
			BWD-CTP-FF-TB	CH-B TEMPERATURE SENSOR/TRANSMITTER FAILS	1.20E-04
			BWD-RPS-TM-CHA	CHANNEL A TEST AND MAINTENANCE	1.60E-02
			BWD-RYL-FF-TRC	TRIP RELAY C FAILS	2.10E-05
30	0	1.20E-14	BWD-CBI-FF-PB	CH-B PRESSURE OUTPUT BISTABLE FAILS	2.90E-04
			BWD-CTP-FF-TB	CH-B TEMPERATURE SENSOR/TRANSMITTER FAILS	1.20E-04
			BWD-RPS-TM-CHA	CHANNEL A TEST AND MAINTENANCE	1.60E-02
			BWD-RYL-FF-TRD	TRIP RELAY D FAILS	2.10E-05
31	0	1.20E-14	BWD-CBI-FF-PC	CH-C PRESSURE OUTPUT BISTABLE FAILS	2.90E-04
			BWD-CTP-FF-TC	CH-C TEMPERATURE SENSOR/TRANSMITTER FAILS	1.20E-04
			BWD-RPS-TM-CHA	CHANNEL A TEST AND MAINTENANCE	1.60E-02
			BWD-RYL-FF-TRB	TRIP RELAY B FAILS	2.10E-05
32	0	1.20E-14	BWD-CBI-FF-PC	CH-C PRESSURE OUTPUT BISTABLE FAILS	2.90E-04
			BWD-CTP-FF-TC	CH-C TEMPERATURE SENSOR/TRANSMITTER FAILS	1.20E-04
			BWD-RPS-TM-CHA	CHANNEL A TEST AND MAINTENANCE	1.60E-02
			BWD-RYL-FF-TRD	TRIP RELAY D FAILS	2.10E-05
33	0	1.20E-14	BWD-CBI-FF-PD	CH-D PRESSURE OUTPUT BISTABLE FAILS	2.90E-04
			BWD-CTP-FF-TD	CH-D TEMPERATURE SENSOR/TRANSMITTER FAILS	1.20E-04
			BWD-RPS-TM-CHA	CHANNEL A TEST AND MAINTENANCE	1.60E-02
			BWD-RYL-FF-TRB	TRIP RELAY B FAILS	2.10E-05
34	0	1.20E-14	BWD-CBI-FF-PD	CH-D PRESSURE OUTPUT BISTABLE FAILS	2.90E-04
			BWD-CTP-FF-TD	CH-D TEMPERATURE SENSOR/TRANSMITTER FAILS	1.20E-04
			BWD-RPS-TM-CHA	CHANNEL A TEST AND MAINTENANCE	1.60E-02
			BWD-RYL-FF-TRC	TRIP RELAY C FAILS	2.10E-05
35	0	9.10E-15	/BWD-RPS-TM-CHA	CHANNEL A TEST AND MAINTENANCE	9.80E-01
			BWD-RYL-FF-TRA	TRIP RELAY A FAILS	2.10E-05
			BWD-RYL-FF-TRB	TRIP RELAY B FAILS	2.10E-05
			BWD-RYL-FF-TRC	TRIP RELAY C FAILS	2.10E-05
36	0	9.10E-15	/BWD-RPS-TM-CHA	CHANNEL A TEST AND MAINTENANCE	9.80E-01
			BWD-RYL-FF-TRA	TRIP RELAY A FAILS	2.10E-05
			BWD-RYL-FF-TRB	TRIP RELAY B FAILS	2.10E-05
			BWD-RYL-FF-TRD	TRIP RELAY D FAILS	2.10E-05
37	0	9.10E-15	/BWD-RPS-TM-CHA	CHANNEL A TEST AND MAINTENANCE	9.80E-01
			BWD-RYL-FF-TRA	TRIP RELAY A FAILS	2.10E-05
			BWD-RYL-FF-TRC	TRIP RELAY C FAILS	2.10E-05
			BWD-RYL-FF-TRD	TRIP RELAY D FAILS	2.10E-05
38	0	9.10E-15	/BWD-RPS-TM-CHA	CHANNEL A TEST AND MAINTENANCE	9.80E-01
			BWD-RYL-FF-TRB	TRIP RELAY B FAILS	2.10E-05
			BWD-RYL-FF-TRC	TRIP RELAY C FAILS	2.10E-05
			BWD-RYL-FF-TRD	TRIP RELAY D FAILS	2.10E-05
39	0	8.60E-15	BWD-CBI-FF-TB	CH-B TEMPERATURE OUTPUT BISTABLE FAILS	2.90E-04
			BWD-CBI-FF-TC	CH-C TEMPERATURE OUTPUT BISTABLE FAILS	2.90E-04
			BWD-CPR-CF-P2OF3TM	CCF 2 OF 3 PRESSURE SENSORS/TRANSMITTERS (CH-A T&M)	6.40E-06
			BWD-RPS-TM-CHA	CHANNEL A TEST AND MAINTENANCE	1.60E-02

Table F-1. (Continued)

Cut Set	Cut Set %	Cut Set Prob.	Basic Event ^a	Description	Prob.
40	0	8.60E-15	BWD-CBI-FF-TB	CH-B TEMPERATURE OUTPUT BISTABLE FAILS	2.90E-04
			BWD-CBI-FF-TD	CH-D TEMPERATURE OUTPUT BISTABLE FAILS	2.90E-04
			BWD-CPR-CF-P2OF3TM	CCF 2 OF 3 PRESSURE SENSORS/TRANSMITTERS (CH-A T&M)	6.40E-06
			BWD-RPS-TM-CHA	CHANNEL A TEST AND MAINTENANCE	1.60E-02
41	0	8.60E-15	BWD-CBI-FF-TC	CH-C TEMPERATURE OUTPUT BISTABLE FAILS	2.90E-04
			BWD-CBI-FF-TD	CH-D TEMPERATURE OUTPUT BISTABLE FAILS	2.90E-04
			BWD-CPR-CF-P2OF3TM	CCF 2 OF 3 PRESSURE SENSORS/TRANSMITTERS (CH-A T&M)	6.40E-06
			BWD-RPS-TM-CHA	CHANNEL A TEST AND MAINTENANCE	1.60E-02
42	0	6.80E-15	BWD-BME-FO-ACTB-A	AC TRIP BREAKER A LOCAL HARDWARE FAILURE	1.80E-05
			BWD-BME-FO-ACTB-C	AC TRIP BREAKER C LOCAL HARDWARE FAILURE	1.80E-05
			BWD-RYL-FF-DC10	DIVERSE TRIP RELAY C10 FAILS	2.10E-05
43	0	6.80E-15	BWD-BME-FO-ACTB-A	AC TRIP BREAKER A LOCAL HARDWARE FAILURE	1.80E-05
			BWD-BME-FO-ACTB-C	AC TRIP BREAKER C LOCAL HARDWARE FAILURE	1.80E-05
			BWD-RYL-FF-DD10	DIVERSE TRIP RELAY D10 FAILS	2.10E-05
44	0	6.80E-15	BWD-BME-FO-ACTB-B	AC TRIP BREAKER B LOCAL HARDWARE FAILURE	1.80E-05
			BWD-BME-FO-ACTB-D	AC TRIP BREAKER D LOCAL HARDWARE FAILURE	1.80E-05
			BWD-RYL-FF-DC10	DIVERSE TRIP RELAY C10 FAILS	2.10E-05
45	0	6.80E-15	BWD-BME-FO-ACTB-B	AC TRIP BREAKER B LOCAL HARDWARE FAILURE	1.80E-05
			BWD-BME-FO-ACTB-D	AC TRIP BREAKER D LOCAL HARDWARE FAILURE	1.80E-05
			BWD-RYL-FF-DD10	DIVERSE TRIP RELAY D10 FAILS	2.10E-05
46	0	6.70E-15	BWD-CBI-FF-PB	CH-B PRESSURE OUTPUT BISTABLE FAILS	2.90E-04
			BWD-CBI-FF-PC	CH-C PRESSURE OUTPUT BISTABLE FAILS	2.90E-04
			BWD-CTP-CF-T2OF3TM	CCF 2 OF 3 TEMPERATURE SENSORS/TRANSMITTERS (CH-A T&M)	4.90E-06
			BWD-RPS-TM-CHA	CHANNEL A TEST AND MAINTENANCE	1.60E-02
47	0	6.70E-15	BWD-CBI-FF-PB	CH-B PRESSURE OUTPUT BISTABLE FAILS	2.90E-04
			BWD-CBI-FF-PD	CH-D PRESSURE OUTPUT BISTABLE FAILS	2.90E-04
			BWD-CTP-CF-T2OF3TM	CCF 2 OF 3 TEMPERATURE SENSORS/TRANSMITTERS (CH-A T&M)	4.90E-06
			BWD-RPS-TM-CHA	CHANNEL A TEST AND MAINTENANCE	1.60E-02
48	0	6.70E-15	BWD-CBI-FF-PC	CH-C PRESSURE OUTPUT BISTABLE FAILS	2.90E-04
			BWD-CBI-FF-PD	CH-D PRESSURE OUTPUT BISTABLE FAILS	2.90E-04
			BWD-CTP-CF-T2OF3TM	CCF 2 OF 3 TEMPERATURE SENSORS/TRANSMITTERS (CH-A T&M)	4.90E-06
			BWD-RPS-TM-CHA	CHANNEL A TEST AND MAINTENANCE	1.60E-02
49	0	6.50E-15	BWD-CPR-FF-PB	CH-B PRESSURE SENSOR/TRANSMITTER FAILS	1.60E-04
			BWD-CTP-FF-TB	CH-B TEMPERATURE SENSOR/TRANSMITTER FAILS	1.20E-04
			BWD-RPS-TM-CHA	CHANNEL A TEST AND MAINTENANCE	1.60E-02
			BWD-RYL-FF-TRC	TRIP RELAY C FAILS	2.10E-05
50	0	6.50E-15	BWD-CPR-FF-PB	CH-B PRESSURE SENSOR/TRANSMITTER FAILS	1.60E-04
			BWD-CTP-FF-TB	CH-B TEMPERATURE SENSOR/TRANSMITTER FAILS	1.20E-04
			BWD-RPS-TM-CHA	CHANNEL A TEST AND MAINTENANCE	1.60E-02
			BWD-RYL-FF-TRD	TRIP RELAY D FAILS	2.10E-05

- a. A / as the first character in a basic event name indicates a complemented event (Success = 1 - Failure). For example, the basic event for channel A in test and maintenance (T&M) is BWD-RPS-TM-CHA (Failure = 1.60E-02). Thus, the basic event name for channel A not in T&M is /BWD-RPS-TM-CHA (Success = 9.84E-01). The event description for complemented events remains the same as the description used for the failure event.

Appendix F

Table F-2. Importance measures sorted on Fussell-Vesely for Davis-Besse (no manual scram).

Basic Event Name	Probability of Failure	Fussell-Vesely Importance	Risk Reduction Ratio	Risk Increase Ratio	Birnbaum Importance
BWD-ROD-CF-RODS	8.40E-07	5.19E-01	2.08E+00	6.18E+05	1.00E+00
BWD-CBI-CF-CBI6OF8	3.97E-07	2.41E-01	1.32E+00	6.08E+05	9.84E-01
BWD-RYL-CF-TR3OF4	3.29E-07	2.00E-01	1.25E+00	6.08E+05	9.84E-01
BWD-RYL-CF-LR9OF16	3.32E-08	2.02E-02	1.02E+00	6.08E+05	9.84E-01
BWD-RPS-TM-CHA	1.60E-02	1.23E-02	1.01E+00	1.75E+00	1.24E-06
BWD-RYL-CF-TR2OF3TM	1.07E-06	1.06E-02	1.01E+00	9.88E+03	1.60E-02
BWD-CBI-CF-CBI4OF6TM	8.70E-07	8.60E-03	1.01E+00	9.88E+03	1.60E-02
BWD-RYL-CF-LR6OF12TM	5.85E-08	5.78E-04	1.00E+00	9.88E+03	1.60E-02
BWD-BME-CF-TB2OF4	7.07E-07	1.87E-05	1.00E+00	2.75E+01	4.29E-05
BWD-RYL-FF-DD10	2.10E-05	9.18E-06	1.00E+00	1.44E+00	7.08E-07
BWD-RYL-FF-DC10	2.10E-05	9.18E-06	1.00E+00	1.44E+00	7.08E-07
BWD-RYL-FF-TRB	2.10E-05	8.81E-06	1.00E+00	1.42E+00	6.79E-07
BWD-RYL-FF-TRC	2.10E-05	8.81E-06	1.00E+00	1.42E+00	6.79E-07
BWD-RYL-FF-TRD	2.10E-05	8.81E-06	1.00E+00	1.42E+00	6.79E-07
BWD-CTP-CF-T3OF4	1.52E-06	1.89E-06	1.00E+00	2.25E+00	2.02E-06
BWD-CPR-CF-P3OF4	2.05E-06	1.89E-06	1.00E+00	1.92E+00	1.50E-06
BWD-RYL-CF-LR3OF8	8.43E-07	3.62E-07	1.00E+00	1.43E+00	6.96E-07
BWD-CPR-CF-P2OF3TM	6.38E-06	3.44E-07	1.00E+00	1.05E+00	8.73E-08
BWD-CTP-CF-T2OF3TM	4.95E-06	3.42E-07	1.00E+00	1.07E+00	1.12E-07
BWD-CBI-FF-TB	2.90E-04	6.91E-08	1.00E+00	1.00E+00	3.86E-10
BWD-CBI-FF-TC	2.90E-04	6.91E-08	1.00E+00	1.00E+00	3.86E-10
BWD-CBI-FF-TD	2.90E-04	6.91E-08	1.00E+00	1.00E+00	3.86E-10
BWD-CBI-FF-PC	2.90E-04	6.21E-08	1.00E+00	1.00E+00	3.47E-10
BWD-CBI-FF-PB	2.90E-04	6.21E-08	1.00E+00	1.00E+00	3.47E-10
BWD-CBI-FF-PD	2.90E-04	6.21E-08	1.00E+00	1.00E+00	3.47E-10
BWD-CPR-FF-PB	1.60E-04	3.42E-08	1.00E+00	1.00E+00	3.47E-10
BWD-CPR-FF-PD	1.60E-04	3.42E-08	1.00E+00	1.00E+00	3.47E-10
BWD-CPR-FF-PC	1.60E-04	3.42E-08	1.00E+00	1.00E+00	3.47E-10
BWD-CTP-FF-TD	1.20E-04	2.85E-08	1.00E+00	1.00E+00	3.86E-10
BWD-CTP-FF-TB	1.20E-04	2.85E-08	1.00E+00	1.00E+00	3.86E-10
BWD-CTP-FF-TC	1.20E-04	2.85E-08	1.00E+00	1.00E+00	3.86E-10
BWD-RYL-CF-LR2OF6TM	2.51E-06	1.76E-08	1.00E+00	1.01E+00	1.13E-08
BWD-RYL-FF-TRA	2.10E-05	1.69E-08	1.00E+00	1.00E+00	1.30E-09
BWD-BME-FO-ACTB-A	1.80E-05	8.37E-09	1.00E+00	1.00E+00	7.56E-10
BWD-BME-FO-ACTB-D	1.80E-05	8.37E-09	1.00E+00	1.00E+00	7.56E-10
BWD-BME-FO-ACTB-C	1.80E-05	8.37E-09	1.00E+00	1.00E+00	7.56E-10
BWD-BME-FO-ACTB-B	1.80E-05	8.37E-09	1.00E+00	1.00E+00	7.56E-10
BWD-BSN-CF-TB2OF4	2.32E-05	4.53E-09	1.00E+00	1.00E+00	3.16E-10
BWD-BUV-CF-TB2OF4	7.52E-06	4.53E-09	1.00E+00	1.00E+00	9.74E-10

Table F-3. Importance measures sorted on Risk Increase for Davis-Besse (no manual scram).

Basic Event Name	Probability of Failure	Fussell-Vesely Importance	Risk Reduction Ratio	Risk Increase Ratio	Birnbaum Importance
BWD-RYL-CF-TR2OF3TM	1.07E-06	1.06E-02	1.01E+00	9.88E+03	1.60E-02
BWD-CBI-CF-CBI4OF6TM	8.70E-07	8.60E-03	1.01E+00	9.88E+03	1.60E-02
BWD-RYL-CF-LR6OF12TM	5.85E-08	5.78E-04	1.00E+00	9.88E+03	1.60E-02
BWD-ROD-CF-RODS	8.40E-07	5.19E-01	2.08E+00	6.18E+05	1.00E+00
BWD-CBI-CF-CBI6OF8	3.97E-07	2.41E-01	1.32E+00	6.08E+05	9.84E-01
BWD-RYL-CF-TR3OF4	3.29E-07	2.00E-01	1.25E+00	6.08E+05	9.84E-01
BWD-RYL-CF-LR9OF16	3.32E-08	2.02E-02	1.02E+00	6.08E+05	9.84E-01
BWD-BME-CF-TB2OF4	7.07E-07	1.87E-05	1.00E+00	2.75E+01	4.29E-05
BWD-CTP-CF-T3OF4	1.52E-06	1.89E-06	1.00E+00	2.25E+00	2.02E-06
BWD-CPR-CF-P3OF4	2.05E-06	1.89E-06	1.00E+00	1.92E+00	1.50E-06
BWD-RPS-TM-CHA	1.60E-02	1.23E-02	1.01E+00	1.75E+00	1.24E-06
BWD-RYL-FF-DD10	2.10E-05	9.18E-06	1.00E+00	1.44E+00	7.08E-07
BWD-RYL-FF-DC10	2.10E-05	9.18E-06	1.00E+00	1.44E+00	7.08E-07
BWD-RYL-CF-LR3OF8	8.43E-07	3.62E-07	1.00E+00	1.43E+00	6.96E-07
BWD-RYL-FF-TRB	2.10E-05	8.81E-06	1.00E+00	1.42E+00	6.79E-07
BWD-RYL-FF-TRC	2.10E-05	8.81E-06	1.00E+00	1.42E+00	6.79E-07
BWD-RYL-FF-TRD	2.10E-05	8.81E-06	1.00E+00	1.42E+00	6.79E-07
BWD-CTP-CF-T2OF3TM	4.95E-06	3.42E-07	1.00E+00	1.07E+00	1.12E-07
BWD-CPR-CF-P2OF3TM	6.38E-06	3.44E-07	1.00E+00	1.05E+00	8.73E-08
BWD-RYL-CF-LR2OF6TM	2.51E-06	1.76E-08	1.00E+00	1.01E+00	1.13E-08
BWD-CBI-FF-TB	2.90E-04	6.91E-08	1.00E+00	1.00E+00	3.86E-10
BWD-CBI-FF-TC	2.90E-04	6.91E-08	1.00E+00	1.00E+00	3.86E-10
BWD-CBI-FF-TD	2.90E-04	6.91E-08	1.00E+00	1.00E+00	3.86E-10
BWD-CBI-FF-PC	2.90E-04	6.21E-08	1.00E+00	1.00E+00	3.47E-10
BWD-CBI-FF-PB	2.90E-04	6.21E-08	1.00E+00	1.00E+00	3.47E-10
BWD-CBI-FF-PD	2.90E-04	6.21E-08	1.00E+00	1.00E+00	3.47E-10
BWD-CPR-FF-PB	1.60E-04	3.42E-08	1.00E+00	1.00E+00	3.47E-10
BWD-CPR-FF-PD	1.60E-04	3.42E-08	1.00E+00	1.00E+00	3.47E-10
BWD-CPR-FF-PC	1.60E-04	3.42E-08	1.00E+00	1.00E+00	3.47E-10
BWD-CTP-FF-TD	1.20E-04	2.85E-08	1.00E+00	1.00E+00	3.86E-10
BWD-CTP-FF-TB	1.20E-04	2.85E-08	1.00E+00	1.00E+00	3.86E-10
BWD-CTP-FF-TC	1.20E-04	2.85E-08	1.00E+00	1.00E+00	3.86E-10
BWD-RYL-FF-TRA	2.10E-05	1.69E-08	1.00E+00	1.00E+00	1.30E-09
BWD-BME-FO-ACTB-A	1.80E-05	8.37E-09	1.00E+00	1.00E+00	7.56E-10
BWD-BME-FO-ACTB-D	1.80E-05	8.37E-09	1.00E+00	1.00E+00	7.56E-10
BWD-BME-FO-ACTB-C	1.80E-05	8.37E-09	1.00E+00	1.00E+00	7.56E-10
BWD-BME-FO-ACTB-B	1.80E-05	8.37E-09	1.00E+00	1.00E+00	7.56E-10
BWD-BSN-CF-TB2OF4	2.32E-05	4.53E-09	1.00E+00	1.00E+00	3.16E-10
BWD-BUV-CF-TB2OF4	7.52E-06	4.53E-09	1.00E+00	1.00E+00	9.74E-10

Appendix F

Table F-4. Importance measures sorted on Birnbaum for Davis-Besse (no manual scram).

Basic Event Name	Probability of Failure	Fussell-Vesely Importance	Risk Reduction Ratio	Risk Increase Ratio	Birnbaum Importance
BWD-ROD-CF-RODS	8.40E-07	5.19E-01	2.08E+00	6.18E+05	1.00E+00
BWD-CBI-CF-CBI6OF8	3.97E-07	2.41E-01	1.32E+00	6.08E+05	9.84E-01
BWD-RYL-CF-TR3OF4	3.29E-07	2.00E-01	1.25E+00	6.08E+05	9.84E-01
BWD-RYL-CF-LR9OF16	3.32E-08	2.02E-02	1.02E+00	6.08E+05	9.84E-01
BWD-RYL-CF-TR2OF3TM	1.07E-06	1.06E-02	1.01E+00	9.88E+03	1.60E-02
BWD-CBI-CF-CBI4OF6TM	8.70E-07	8.60E-03	1.01E+00	9.88E+03	1.60E-02
BWD-RYL-CF-LR6OF12TM	5.85E-08	5.78E-04	1.00E+00	9.88E+03	1.60E-02
BWD-BME-CF-TB2OF4	7.07E-07	1.87E-05	1.00E+00	2.75E+01	4.29E-05
BWD-CTP-CF-T3OF4	1.52E-06	1.89E-06	1.00E+00	2.25E+00	2.02E-06
BWD-CPR-CF-P3OF4	2.05E-06	1.89E-06	1.00E+00	1.92E+00	1.50E-06
BWD-RPS-TM-CHA	1.60E-02	1.23E-02	1.01E+00	1.75E+00	1.24E-06
BWD-RYL-FF-DD10	2.10E-05	9.18E-06	1.00E+00	1.44E+00	7.08E-07
BWD-RYL-FF-DC10	2.10E-05	9.18E-06	1.00E+00	1.44E+00	7.08E-07
BWD-RYL-CF-LR3OF8	8.43E-07	3.62E-07	1.00E+00	1.43E+00	6.96E-07
BWD-RYL-FF-TRB	2.10E-05	8.81E-06	1.00E+00	1.42E+00	6.79E-07
BWD-RYL-FF-TRC	2.10E-05	8.81E-06	1.00E+00	1.42E+00	6.79E-07
BWD-RYL-FF-TRD	2.10E-05	8.81E-06	1.00E+00	1.42E+00	6.79E-07
BWD-CTP-CF-T2OF3TM	4.95E-06	3.42E-07	1.00E+00	1.07E+00	1.12E-07
BWD-CPR-CF-P2OF3TM	6.38E-06	3.44E-07	1.00E+00	1.05E+00	8.73E-08
BWD-RYL-CF-LR2OF6TM	2.51E-06	1.76E-08	1.00E+00	1.01E+00	1.13E-08
BWD-RYL-FF-TRA	2.10E-05	1.69E-08	1.00E+00	1.00E+00	1.30E-09
BWD-BUV-CF-TB2OF4	7.52E-06	4.53E-09	1.00E+00	1.00E+00	9.74E-10
BWD-BME-FO-ACTB-A	1.80E-05	8.37E-09	1.00E+00	1.00E+00	7.56E-10
BWD-BME-FO-ACTB-D	1.80E-05	8.37E-09	1.00E+00	1.00E+00	7.56E-10
BWD-BME-FO-ACTB-C	1.80E-05	8.37E-09	1.00E+00	1.00E+00	7.56E-10
BWD-BME-FO-ACTB-B	1.80E-05	8.37E-09	1.00E+00	1.00E+00	7.56E-10
BWD-CBI-FF-TB	2.90E-04	6.91E-08	1.00E+00	1.00E+00	3.86E-10
BWD-CBI-FF-TC	2.90E-04	6.91E-08	1.00E+00	1.00E+00	3.86E-10
BWD-CBI-FF-TD	2.90E-04	6.91E-08	1.00E+00	1.00E+00	3.86E-10
BWD-CTP-FF-TD	1.20E-04	2.85E-08	1.00E+00	1.00E+00	3.86E-10
BWD-CTP-FF-TB	1.20E-04	2.85E-08	1.00E+00	1.00E+00	3.86E-10
BWD-CTP-FF-TC	1.20E-04	2.85E-08	1.00E+00	1.00E+00	3.86E-10
BWD-CBI-FF-PC	2.90E-04	6.21E-08	1.00E+00	1.00E+00	3.47E-10
BWD-CBI-FF-PB	2.90E-04	6.21E-08	1.00E+00	1.00E+00	3.47E-10
BWD-CBI-FF-PD	2.90E-04	6.21E-08	1.00E+00	1.00E+00	3.47E-10
BWD-CPR-FF-PB	1.60E-04	3.42E-08	1.00E+00	1.00E+00	3.47E-10
BWD-CPR-FF-PD	1.60E-04	3.42E-08	1.00E+00	1.00E+00	3.47E-10
BWD-CPR-FF-PC	1.60E-04	3.42E-08	1.00E+00	1.00E+00	3.47E-10
BWD-BSN-CF-TB2OF4	2.32E-05	4.53E-09	1.00E+00	1.00E+00	3.16E-10

Table F-5. RPS B&W Davis-Besse top 50 cutsets (manual scram).

Cut Set	Cut Set %	Cut Set Prob.	Basic Event*	Description	Prob.
1	99.1	8.40E-07	BWD-ROD-CF-RODS	CCF 20% OR MORE CRD/RODS FAIL TO INSERT	8.40E-07
2	0.5	3.90E-09	BWD-CBI-CF-CBI6OF8	CCF SPECIFIC 6 OF 8 OUTPUT BISTABLES	4.00E-07
			/BWD-RPS-TM-CHA	CHANNEL A TEST AND MAINTENANCE	9.80E-01
			BWD-XHE-XE-SCRAM	OPERATOR FAILS TO INITIATE MANUAL SCRAM	1.00E-02
3	0.4	3.20E-09	/BWD-RPS-TM-CHA	CHANNEL A TEST AND MAINTENANCE	9.80E-01
			BWD-RYL-CF-TR3OF4	CCF 3 OF 4 TRIP RELAYS	3.30E-07
			BWD-XHE-XE-SCRAM	OPERATOR FAILS TO INITIATE MANUAL SCRAM	1.00E-02
4	0	3.30E-10	/BWD-RPS-TM-CHA	CHANNEL A TEST AND MAINTENANCE	9.80E-01
			BWD-RYL-CF-LR9OF16	CCF SPECIFIC 9 OF 16 LOGIC RELAYS	3.30E-08
			BWD-XHE-XE-SCRAM	OPERATOR FAILS TO INITIATE MANUAL SCRAM	1.00E-02
5	0	1.70E-10	BWD-RPS-TM-CHA	CHANNEL A TEST AND MAINTENANCE	1.60E-02
			BWD-RYL-CF-TR2OF3TM	CCF 2 OF 3 TRIP RELAYS (CH-A T&M)	1.10E-06
			BWD-XHE-XE-SCRAM	OPERATOR FAILS TO INITIATE MANUAL SCRAM	1.00E-02
6	0	1.40E-10	BWD-CBI-CF-CBI4OF6TM	CCF SPECIFIC 4 OF 6 OUTPUT BISTABLES (CH-A T&M)	8.70E-07
			BWD-RPS-TM-CHA	CHANNEL A TEST AND MAINTENANCE	1.60E-02
			BWD-XHE-XE-SCRAM	OPERATOR FAILS TO INITIATE MANUAL SCRAM	1.00E-02
7	0	1.50E-11	BWD-BME-CF-TB2OF4	CCF 2 OF 4 (1-OUT-OF-2 TWICE) TRIP BREAKERS	7.10E-07
			BWD-RYL-FF-DC10	DIVERSE TRIP RELAY C10 FAILS	2.10E-05
8	0	1.50E-11	BWD-BME-CF-TB2OF4	CCF 2 OF 4 (1-OUT-OF-2 TWICE) TRIP BREAKERS	7.10E-07
			BWD-RYL-FF-DD10	DIVERSE TRIP RELAY D10 FAILS	2.10E-05
9	0	9.40E-12	BWD-RPS-TM-CHA	CHANNEL A TEST AND MAINTENANCE	1.60E-02
			BWD-RYL-CF-LR6OF12TM	CCF SPECIFIC 6 OF 12 LOGIC RELAYS (CH-A T&M)	5.80E-08
			BWD-XHE-XE-SCRAM	OPERATOR FAILS TO INITIATE MANUAL SCRAM	1.00E-02
10	0	2.10E-12	BWD-CBI-CF-CBI6OF8	CCF SPECIFIC 6 OF 8 OUTPUT BISTABLES	4.00E-07
			BWD-MSW-CF-2OF4	CCF 2 OF 4 (1-OUT-OF-2 TWICE) MANUAL SWITCH	5.40E-06
			/BWD-RPS-TM-CHA	CHANNEL A TEST AND MAINTENANCE	9.80E-01
11	0	1.80E-12	BWD-MSW-CF-2OF4	CCF 2 OF 4 (1-OUT-OF-2 TWICE) MANUAL SWITCH	5.40E-06
			/BWD-RPS-TM-CHA	CHANNEL A TEST AND MAINTENANCE	9.80E-01
			BWD-RYL-CF-TR3OF4	CCF 3 OF 4 TRIP RELAYS	3.30E-07
12	0	1.80E-13	BWD-MSW-CF-2OF4	CCF 2 OF 4 (1-OUT-OF-2 TWICE) MANUAL SWITCH	5.40E-06
			/BWD-RPS-TM-CHA	CHANNEL A TEST AND MAINTENANCE	9.80E-01
			BWD-RYL-CF-LR9OF16	CCF SPECIFIC 9 OF 16 LOGIC RELAYS	3.30E-08
13	0	9.30E-14	BWD-MSW-CF-2OF4	CCF 2 OF 4 (1-OUT-OF-2 TWICE) MANUAL SWITCH	5.40E-06
			BWD-RPS-TM-CHA	CHANNEL A TEST AND MAINTENANCE	1.60E-02
			BWD-RYL-CF-TR2OF3TM	CCF 2 OF 3 TRIP RELAYS (CH-A T&M)	1.10E-06
14	0	7.60E-14	BWD-CBI-CF-CBI4OF6TM	CCF SPECIFIC 4 OF 6 OUTPUT BISTABLES (CH-A T&M)	8.70E-07
			BWD-MSW-CF-2OF4	CCF 2 OF 4 (1-OUT-OF-2 TWICE) MANUAL SWITCH	5.40E-06
			BWD-RPS-TM-CHA	CHANNEL A TEST AND MAINTENANCE	1.60E-02
15	0	7.10E-14	BWD-RPS-TM-CHA	CHANNEL A TEST AND MAINTENANCE	1.60E-02
			BWD-RYL-FF-TRB	TRIP RELAY B FAILS	2.10E-05
			BWD-RYL-FF-TRC	TRIP RELAY C FAILS	2.10E-05
			BWD-XHE-XE-SCRAM	OPERATOR FAILS TO INITIATE MANUAL SCRAM	1.00E-02
16	0	7.10E-14	BWD-RPS-TM-CHA	CHANNEL A TEST AND MAINTENANCE	1.60E-02
			BWD-RYL-FF-TRB	TRIP RELAY B FAILS	2.10E-05
			BWD-RYL-FF-TRD	TRIP RELAY D FAILS	2.10E-05
			BWD-XHE-XE-SCRAM	OPERATOR FAILS TO INITIATE MANUAL SCRAM	1.00E-02
17	0	7.10E-14	BWD-RPS-TM-CHA	CHANNEL A TEST AND MAINTENANCE	1.60E-02
			BWD-RYL-FF-TRC	TRIP RELAY C FAILS	2.10E-05
			BWD-RYL-FF-TRD	TRIP RELAY D FAILS	2.10E-05
			BWD-XHE-XE-SCRAM	OPERATOR FAILS TO INITIATE MANUAL SCRAM	1.00E-02
18	0	3.10E-14	BWD-CPR-CF-P3OF4	CCF 3 OF 4 PRESSURE SENSORS/TRANSMITTERS	2.00E-06
			BWD-CTP-CF-T3OF4	CCF 3 OF 4 TEMPERATURE SENSORS/TRANSMITTERS	1.50E-06
			/BWD-RPS-TM-CHA	CHANNEL A TEST AND MAINTENANCE	9.80E-01
			BWD-XHE-XE-SCRAM	OPERATOR FAILS TO INITIATE MANUAL SCRAM	1.00E-02
19	0	6.80E-15	BWD-BME-FO-ACTB-A	AC TRIP BREAKER A LOCAL HARDWARE FAILURE	1.80E-05
			BWD-BME-FO-ACTB-C	AC TRIP BREAKER C LOCAL HARDWARE FAILURE	1.80E-05
			BWD-RYL-FF-DC10	DIVERSE TRIP RELAY C10 FAILS	2.10E-05
20	0	6.80E-15	BWD-BME-FO-ACTB-A	AC TRIP BREAKER A LOCAL HARDWARE FAILURE	1.80E-05
			BWD-BME-FO-ACTB-C	AC TRIP BREAKER C LOCAL HARDWARE FAILURE	1.80E-05
			BWD-RYL-FF-DD10	DIVERSE TRIP RELAY D10 FAILS	2.10E-05
21	0	6.80E-15	BWD-BME-FO-ACTB-B	AC TRIP BREAKER B LOCAL HARDWARE FAILURE	1.80E-05
			BWD-BME-FO-ACTB-D	AC TRIP BREAKER D LOCAL HARDWARE FAILURE	1.80E-05
			BWD-RYL-FF-DC10	DIVERSE TRIP RELAY C10 FAILS	2.10E-05
22	0	6.80E-15	BWD-BME-FO-ACTB-B	AC TRIP BREAKER B LOCAL HARDWARE FAILURE	1.80E-05
			BWD-BME-FO-ACTB-D	AC TRIP BREAKER D LOCAL HARDWARE FAILURE	1.80E-05

Appendix F

Table F-5. (Continued)

Cut Set	Cut Set %	Cut Set Prob.	Basic Event ^a	Description	Prob.
23	0	6.60E-15	BWD-RYL-FF-DD10	DIVERSE TRIP RELAY D10 FAILS	2.10E-05
			BWD-CBI-CF-CBI6OF8	CCF SPECIFIC 6 OF 8 OUTPUT BISTABLES	4.00E-07
			BWD-MSW-FF-MT1	MANUAL SWITCH 1 FAILS	1.30E-04
			BWD-MSW-FF-MT3	MANUAL SWITCH 3 FAILS	1.30E-04
24	0	6.60E-15	/BWD-RPS-TM-CHA	CHANNEL A TEST AND MAINTENANCE	9.80E-01
			BWD-CBI-CF-CBI6OF8	CCF SPECIFIC 6 OF 8 OUTPUT BISTABLES	4.00E-07
			BWD-MSW-FF-MT2	MANUAL SWITCH 2 FAILS	1.30E-04
			BWD-MSW-FF-MT4	MANUAL SWITCH 4 FAILS	1.30E-04
25	0	5.90E-15	/BWD-RPS-TM-CHA	CHANNEL A TEST AND MAINTENANCE	9.80E-01
			BWD-BME-CF-TB2OF4	CCF 2 OF 4 (1-OUT-OF-2 TWICE) TRIP BREAKERS	7.10E-07
			/BWD-RPS-TM-CHA	CHANNEL A TEST AND MAINTENANCE	9.80E-01
			BWD-RYL-CF-LR3OF8	CCF 3 OF 8 LOGIC RELAYS. CHANNELS C & D ONLY FOR ELEC TRIP	8.40E-07
26	0	5.50E-15	BWD-XHE-XE-SCRAM	OPERATOR FAILS TO INITIATE MANUAL SCRAM	1.00E-02
			BWD-MSW-FF-MT1	MANUAL SWITCH 1 FAILS	1.30E-04
			BWD-MSW-FF-MT3	MANUAL SWITCH 3 FAILS	1.30E-04
			/BWD-RPS-TM-CHA	CHANNEL A TEST AND MAINTENANCE	9.80E-01
27	0	5.50E-15	BWD-RYL-CF-TR3OF4	CCF 3 OF 4 TRIP RELAYS	3.30E-07
			BWD-MSW-FF-MT2	MANUAL SWITCH 2 FAILS	1.30E-04
			BWD-MSW-FF-MT4	MANUAL SWITCH 4 FAILS	1.30E-04
			/BWD-RPS-TM-CHA	CHANNEL A TEST AND MAINTENANCE	9.80E-01
28	0	5.10E-15	BWD-RYL-CF-TR3OF4	CCF 3 OF 4 TRIP RELAYS	3.30E-07
			BWD-MSW-CF-2OF4	CCF 2 OF 4 (1-OUT-OF-2 TWICE) MANUAL SWITCH	5.40E-06
			BWD-RPS-TM-CHA	CHANNEL A TEST AND MAINTENANCE	1.60E-02
			BWD-RYL-CF-LR6OF12TM	CCF SPECIFIC 6 OF 12 LOGIC RELAYS (CH-A T&M)	5.80E-08
29	0	5.10E-15	BWD-CPR-CF-P2OF3TM	CCF 2 OF 3 PRESSURE SENSORS/TRANSMITTERS (CH-A T&M)	6.40E-06
			BWD-CTP-CF-T2OF3TM	CCF 2 OF 3 TEMPERATURE SENSORS/TRANSMITTERS (CH-A T&M)	4.90E-06
			BWD-RPS-TM-CHA	CHANNEL A TEST AND MAINTENANCE	1.60E-02
			BWD-XHE-XE-SCRAM	OPERATOR FAILS TO INITIATE MANUAL SCRAM	1.00E-02
30	0	3.70E-15	BWD-BSN-CF-TB2OF4	CCF 2 OF 4 (1-OF-2 TWICE) TRIP BREAKER SHUNT TRIP DEVICES	2.30E-05
			BWD-BUV-CF-TB2OF4	CCF 2 OF 4 (1-OF-2 TWICE) TRIP BREAKER UNDERVOLTAGE DEVICES	7.50E-06
			BWD-RYL-FF-DC10	DIVERSE TRIP RELAY C10 FAILS	2.10E-05
			BWD-BSN-CF-TB2OF4	CCF 2 OF 4 (1-OF-2 TWICE) TRIP BREAKER SHUNT TRIP DEVICES	2.30E-05
31	0	3.70E-15	BWD-BUV-CF-TB2OF4	CCF 2 OF 4 (1-OF-2 TWICE) TRIP BREAKER UNDERVOLTAGE DEVICES	7.50E-06
			BWD-RYL-FF-DD10	DIVERSE TRIP RELAY D10 FAILS	2.10E-05

- a. A / as the first character in a basic event name indicates a complemented event (Success = 1 - Failure). For example, the basic event for channel A in test and maintenance (T&M) is BWD-RPS-TM-CHA (Failure = 1.60E-02). Thus, the basic event name for channel A not in T&M is /BWD-RPS-TM-CHA (Success = 9.84E-01). The event description for complemented events remains the same as the description used for the failure event.

Table F-6. Importance measures sorted on Fussell-Vesely for Davis-Besse (manual scram).

Basic Event Name	Probability of Failure	Fussell-Vesely Importance	Risk Reduction Ratio	Risk Increase Ratio	Birnbaum Importance
BWD-ROD-CF-RODS	8.40E-07	9.91E-01	1.08E+02	1.18E+06	1.00E+00
BWD-XHE-XE-SCRAM	1.00E-02	9.19E-03	1.01E+00	1.91E+00	7.79E-07
BWD-CBI-CF-CBI6OF8	3.97E-07	4.61E-03	1.01E+00	1.16E+04	9.85E-03
BWD-RYL-CF-TR3OF4	3.29E-07	3.82E-03	1.00E+00	1.16E+04	9.85E-03
BWD-RYL-CF-LR9OF16	3.32E-08	3.86E-04	1.00E+00	1.16E+04	9.85E-03
BWD-RPS-TM-CHA	1.60E-02	2.34E-04	1.00E+00	1.01E+00	1.24E-08
BWD-RYL-CF-TR2OF3TM	1.07E-06	2.02E-04	1.00E+00	1.90E+02	1.60E-04
BWD-CBI-CF-CBI4OF6TM	8.70E-07	1.64E-04	1.00E+00	1.90E+02	1.60E-04
BWD-BME-CF-TB2OF4	7.07E-07	3.50E-05	1.00E+00	5.06E+01	4.20E-05
BWD-RYL-FF-DC10	2.10E-05	1.75E-05	1.00E+00	1.84E+00	7.08E-07
BWD-RYL-FF-DD10	2.10E-05	1.75E-05	1.00E+00	1.84E+00	7.08E-07
BWD-RYL-CF-LR6OF12TM	5.85E-08	1.11E-05	1.00E+00	1.90E+02	1.60E-04
BWD-MSW-CF-2OF4	5.43E-06	4.99E-06	1.00E+00	1.92E+00	7.79E-07
BWD-RYL-FF-TRB	2.10E-05	1.67E-07	1.00E+00	1.01E+00	6.72E-09
BWD-RYL-FF-TRC	2.10E-05	1.67E-07	1.00E+00	1.01E+00	6.72E-09
BWD-RYL-FF-TRD	2.10E-05	1.67E-07	1.00E+00	1.01E+00	6.72E-09
BWD-CTP-CF-T3OF4	1.52E-06	3.61E-08	1.00E+00	1.02E+00	2.02E-08
BWD-CPR-CF-P3OF4	2.05E-06	3.61E-08	1.00E+00	1.02E+00	1.50E-08
BWD-BME-FO-ACTB-A	1.80E-05	1.60E-08	1.00E+00	1.00E+00	7.56E-10
BWD-BME-FO-ACTB-D	1.80E-05	1.60E-08	1.00E+00	1.00E+00	7.56E-10
BWD-BME-FO-ACTB-C	1.80E-05	1.60E-08	1.00E+00	1.00E+00	7.56E-10
BWD-BME-FO-ACTB-B	1.80E-05	1.60E-08	1.00E+00	1.00E+00	7.56E-10
BWD-MSW-FF-MT3	1.30E-04	1.41E-08	1.00E+00	1.00E+00	9.29E-11
BWD-MSW-FF-MT2	1.30E-04	1.41E-08	1.00E+00	1.00E+00	9.29E-11
BWD-MSW-FF-MT1	1.30E-04	1.41E-08	1.00E+00	1.00E+00	9.29E-11
BWD-MSW-FF-MT4	1.30E-04	1.41E-08	1.00E+00	1.00E+00	9.29E-11
BWD-BSN-CF-TB2OF4	2.32E-05	8.64E-09	1.00E+00	1.00E+00	3.16E-10
BWD-BUV-CF-TB2OF4	7.52E-06	8.64E-09	1.00E+00	1.00E+00	9.74E-10
BWD-RYL-CF-LR3OF8	8.43E-07	6.94E-09	1.00E+00	1.01E+00	6.96E-09
BWD-CTP-CF-T2OF3TM	4.95E-06	6.02E-09	1.00E+00	1.00E+00	1.02E-09
BWD-CPR-CF-P2OF3TM	6.38E-06	6.02E-09	1.00E+00	1.00E+00	7.92E-10

Appendix F

Table F-7. Importance measures sorted on Risk Increase for Davis-Besse (manual scram).

Basic Event Name	Probability of Failure	Fussell-Vesely Importance	Risk Reduction Ratio	Risk Increase Ratio	Birnbaum Importance
BWD-ROD-CF-RODS	8.40E-07	9.91E-01	1.08E+02	1.18E+06	1.00E+00
BWD-CBI-CF-CBI6OF8	3.97E-07	4.61E-03	1.01E+00	1.16E+04	9.85E-03
BWD-RYL-CF-TR3OF4	3.29E-07	3.82E-03	1.00E+00	1.16E+04	9.85E-03
BWD-RYL-CF-LR9OF16	3.32E-08	3.86E-04	1.00E+00	1.16E+04	9.85E-03
BWD-RYL-CF-TR2OF3TM	1.07E-06	2.02E-04	1.00E+00	1.90E+02	1.60E-04
BWD-CBI-CF-CBI4OF6TM	8.70E-07	1.64E-04	1.00E+00	1.90E+02	1.60E-04
BWD-RYL-CF-LR6OF12TM	5.85E-08	1.11E-05	1.00E+00	1.90E+02	1.60E-04
BWD-BME-CF-TB2OF4	7.07E-07	3.50E-05	1.00E+00	5.06E+01	4.20E-05
BWD-MSW-CF-2OF4	5.43E-06	4.99E-06	1.00E+00	1.92E+00	7.79E-07
BWD-XHE-XE-SCRAM	1.00E-02	9.19E-03	1.01E+00	1.91E+00	7.79E-07
BWD-RYL-FF-DC10	2.10E-05	1.75E-05	1.00E+00	1.84E+00	7.08E-07
BWD-RYL-FF-DD10	2.10E-05	1.75E-05	1.00E+00	1.84E+00	7.08E-07
BWD-CTP-CF-T3OF4	1.52E-06	3.61E-08	1.00E+00	1.02E+00	2.02E-08
BWD-CPR-CF-P3OF4	2.05E-06	3.61E-08	1.00E+00	1.02E+00	1.50E-08
BWD-RPS-TM-CHA	1.60E-02	2.34E-04	1.00E+00	1.01E+00	1.24E-08
BWD-RYL-FF-TRB	2.10E-05	1.67E-07	1.00E+00	1.01E+00	6.72E-09
BWD-RYL-FF-TRC	2.10E-05	1.67E-07	1.00E+00	1.01E+00	6.72E-09
BWD-RYL-FF-TRD	2.10E-05	1.67E-07	1.00E+00	1.01E+00	6.72E-09
BWD-RYL-CF-LR3OF8	8.43E-07	6.94E-09	1.00E+00	1.01E+00	6.96E-09
BWD-BME-FO-ACTB-A	1.80E-05	1.60E-08	1.00E+00	1.00E+00	7.56E-10
BWD-BME-FO-ACTB-D	1.80E-05	1.60E-08	1.00E+00	1.00E+00	7.56E-10
BWD-BME-FO-ACTB-C	1.80E-05	1.60E-08	1.00E+00	1.00E+00	7.56E-10
BWD-BME-FO-ACTB-B	1.80E-05	1.60E-08	1.00E+00	1.00E+00	7.56E-10
BWD-MSW-FF-MT3	1.30E-04	1.41E-08	1.00E+00	1.00E+00	9.29E-11
BWD-MSW-FF-MT2	1.30E-04	1.41E-08	1.00E+00	1.00E+00	9.29E-11
BWD-MSW-FF-MT1	1.30E-04	1.41E-08	1.00E+00	1.00E+00	9.29E-11
BWD-MSW-FF-MT4	1.30E-04	1.41E-08	1.00E+00	1.00E+00	9.29E-11
BWD-BSN-CF-TB2OF4	2.32E-05	8.64E-09	1.00E+00	1.00E+00	3.16E-10
BWD-BUV-CF-TB2OF4	7.52E-06	8.64E-09	1.00E+00	1.00E+00	9.74E-10
BWD-CTP-CF-T2OF3TM	4.95E-06	6.02E-09	1.00E+00	1.00E+00	1.02E-09
BWD-CPR-CF-P2OF3TM	6.38E-06	6.02E-09	1.00E+00	1.00E+00	7.92E-10

Table F-8. Importance measures sorted on Birnbaum for Davis-Besse (manual scram).

Basic Event Name	Probability of Failure	Fussell-Vesely Importance	Risk Reduction Ratio	Risk Increase Ratio	Birnbaum Importance
BWD-ROD-CF-RODS	8.40E-07	9.91E-01	1.08E+02	1.18E+06	1.00E+00
BWD-CBI-CF-CBI6OF8	3.97E-07	4.61E-03	1.01E+00	1.16E+04	9.85E-03
BWD-RYL-CF-TR3OF4	3.29E-07	3.82E-03	1.00E+00	1.16E+04	9.85E-03
BWD-RYL-CF-LR9OF16	3.32E-08	3.86E-04	1.00E+00	1.16E+04	9.85E-03
BWD-RYL-CF-TR2OF3TM	1.07E-06	2.02E-04	1.00E+00	1.90E+02	1.60E-04
BWD-CBI-CF-CBI4OF6TM	8.70E-07	1.64E-04	1.00E+00	1.90E+02	1.60E-04
BWD-RYL-CF-LR6OF12TM	5.85E-08	1.11E-05	1.00E+00	1.90E+02	1.60E-04
BWD-BME-CF-TB2OF4	7.07E-07	3.50E-05	1.00E+00	5.06E+01	4.20E-05
BWD-XHE-XE-SCRAM	1.00E-02	9.19E-03	1.01E+00	1.91E+00	7.79E-07
BWD-MSW-CF-2OF4	5.43E-06	4.99E-06	1.00E+00	1.92E+00	7.79E-07
BWD-RYL-FF-DC10	2.10E-05	1.75E-05	1.00E+00	1.84E+00	7.08E-07
BWD-RYL-FF-DD10	2.10E-05	1.75E-05	1.00E+00	1.84E+00	7.08E-07
BWD-CTP-CF-T3OF4	1.52E-06	3.61E-08	1.00E+00	1.02E+00	2.02E-08
BWD-CPR-CF-P3OF4	2.05E-06	3.61E-08	1.00E+00	1.02E+00	1.50E-08
BWD-RPS-TM-CHA	1.60E-02	2.34E-04	1.00E+00	1.01E+00	1.24E-08
BWD-RYL-CF-LR3OF8	8.43E-07	6.94E-09	1.00E+00	1.01E+00	6.96E-09
BWD-RYL-FF-TRB	2.10E-05	1.67E-07	1.00E+00	1.01E+00	6.72E-09
BWD-RYL-FF-TRC	2.10E-05	1.67E-07	1.00E+00	1.01E+00	6.72E-09
BWD-RYL-FF-TRD	2.10E-05	1.67E-07	1.00E+00	1.01E+00	6.72E-09
BWD-CTP-CF-T2OF3TM	4.95E-06	6.02E-09	1.00E+00	1.00E+00	1.02E-09
BWD-BUV-CF-TB2OF4	7.52E-06	8.64E-09	1.00E+00	1.00E+00	9.74E-10
BWD-CPR-CF-P2OF3TM	6.38E-06	6.02E-09	1.00E+00	1.00E+00	7.92E-10
BWD-BME-FO-ACTB-A	1.80E-05	1.60E-08	1.00E+00	1.00E+00	7.56E-10
BWD-BME-FO-ACTB-D	1.80E-05	1.60E-08	1.00E+00	1.00E+00	7.56E-10
BWD-BME-FO-ACTB-C	1.80E-05	1.60E-08	1.00E+00	1.00E+00	7.56E-10
BWD-BME-FO-ACTB-B	1.80E-05	1.60E-08	1.00E+00	1.00E+00	7.56E-10
BWD-BSN-CF-TB2OF4	2.32E-05	8.64E-09	1.00E+00	1.00E+00	3.16E-10
BWD-MSW-FF-MT3	1.30E-04	1.41E-08	1.00E+00	1.00E+00	9.29E-11
BWD-MSW-FF-MT2	1.30E-04	1.41E-08	1.00E+00	1.00E+00	9.29E-11
BWD-MSW-FF-MT1	1.30E-04	1.41E-08	1.00E+00	1.00E+00	9.29E-11
BWD-MSW-FF-MT4	1.30E-04	1.41E-08	1.00E+00	1.00E+00	9.29E-11

Appendix F

Table F-9. RPS B&W Oconee top 50 cutsets (no manual scram).

Cut Set	Cut Set %	Cut Set Prob.	Basic Event a	Description	Prob.
1	50.1	3.90E-07	BWO-CBI-CF-CBI6OF8	CCF SPECIFIC 6 OF 8 OUTPUT BISTABLES	4.00E-07
			/BWO-RPS-TM-CHA	CHANNEL A TEST AND MAINTENANCE	9.80E-01
2	41.5	3.20E-07	/BWO-RPS-TM-CHA	CHANNEL A TEST AND MAINTENANCE	9.80E-01
			BWO-RYL-CF-TR3OF4	CCF 3 OF 4 TRIP RELAYS	3.30E-07
3	4.2	3.30E-08	/BWO-RPS-TM-CHA	CHANNEL A TEST AND MAINTENANCE	9.80E-01
			BWO-RYL-CF-LR9OF16	CCF SPECIFIC 9 OF 16 LOGIC RELAYS	3.30E-08
4	2.2	1.70E-08	BWO-RPS-TM-CHA	CHANNEL A TEST AND MAINTENANCE	1.60E-02
			BWO-RYL-CF-TR2OF3TM	CCF 2 OF 3 TRIP RELAYS CH-A TM	1.10E-06
5	1.8	1.40E-08	BWO-CBI-CF-CBI4OF6TM	CCF SPECIFIC 4 OF 6 OUTPUT BISTABLES CH-A TM	8.70E-07
			BWO-RPS-TM-CHA	CHANNEL A TEST AND MAINTENANCE	1.60E-02
6	0.1	9.40E-10	BWO-RPS-TM-CHA	CHANNEL A TEST AND MAINTENANCE	1.60E-02
			BWO-RYL-CF-LR6OF12TM	CCF 6 OF 12 TRIP RELAYS (CH A IN T&M)	5.80E-08
7	0.1	3.60E-10	BWO-BME-CF-TB3OF6-4G	CCF OF 2 OR MORE OF 6 RTBS	1.10E-06
			BWO-RMA-FF-1OF20REG	1 REGULATING ROD OUT OF 20 FAILS TO INSERT	3.40E-04
8	0	2.90E-10	BWO-RMA-FF-1OF20REG	1 REGULATING ROD OUT OF 20 FAILS TO INSERT	3.40E-04
			BWO-ROD-CF-RODS	ROD CCF, 20% OF RODS FAIL TO INSERT	8.40E-07
9	0	2.20E-11	BWO-BME-CF-TB3OF6-4G	CCF OF 2 OR MORE OF 6 RTBS	1.10E-06
			BWO-RYL-FF-ETE2	ELECTRONIC TRIP RELAY E FOR GROUP 5 FAILS	2.10E-05
10	0	2.20E-11	BWO-BME-CF-TB3OF6-4G	CCF OF 2 OR MORE OF 6 RTBS	1.10E-06
			BWO-RYL-FF-ETE3	ELECTRONIC TRIP RELAY E FOR GROUP 6 FAILS	2.10E-05
11	0	2.20E-11	BWO-BME-CF-TB3OF6-4G	CCF OF 2 OR MORE OF 6 RTBS	1.10E-06
			BWO-RYL-FF-ETE4	ELECTRONIC TRIP RELAY E FOR GROUP 7 FAILS	2.10E-05
12	0	2.20E-11	BWO-BME-CF-TB3OF6-4G	CCF OF 2 OR MORE OF 6 RTBS	1.10E-06
			BWO-RYL-FF-ETF2	ELECTRONIC TRIP RELAY F FOR GROUP 5 FAILS	2.10E-05
13	0	2.20E-11	BWO-BME-CF-TB3OF6-4G	CCF OF 2 OR MORE OF 6 RTBS	1.10E-06
			BWO-RYL-FF-ETF3	ELECTRONIC TRIP RELAY F FOR GROUP 6 FAILS	2.10E-05
14	0	2.20E-11	BWO-BME-CF-TB3OF6-4G	CCF OF 2 OR MORE OF 6 RTBS	1.10E-06
			BWO-RYL-FF-ETF4	ELECTRONIC TRIP RELAY F FOR GROUP 7 FAILS	2.10E-05
15	0	1.80E-11	BWO-ROD-CF-RODS	ROD CCF, 20% OF RODS FAIL TO INSERT	8.40E-07
			BWO-RYL-FF-ETE2	ELECTRONIC TRIP RELAY E FOR GROUP 5 FAILS	2.10E-05
16	0	1.80E-11	BWO-ROD-CF-RODS	ROD CCF, 20% OF RODS FAIL TO INSERT	8.40E-07
			BWO-RYL-FF-ETE3	ELECTRONIC TRIP RELAY E FOR GROUP 6 FAILS	2.10E-05
17	0	1.80E-11	BWO-ROD-CF-RODS	ROD CCF, 20% OF RODS FAIL TO INSERT	8.40E-07
			BWO-RYL-FF-ETE4	ELECTRONIC TRIP RELAY E FOR GROUP 7 FAILS	2.10E-05
18	0	1.80E-11	BWO-ROD-CF-RODS	ROD CCF, 20% OF RODS FAIL TO INSERT	8.40E-07
			BWO-RYL-FF-ETF2	ELECTRONIC TRIP RELAY F FOR GROUP 5 FAILS	2.10E-05
19	0	1.80E-11	BWO-ROD-CF-RODS	ROD CCF, 20% OF RODS FAIL TO INSERT	8.40E-07
			BWO-RYL-FF-ETF3	ELECTRONIC TRIP RELAY F FOR GROUP 6 FAILS	2.10E-05
20	0	1.80E-11	BWO-ROD-CF-RODS	ROD CCF, 20% OF RODS FAIL TO INSERT	8.40E-07
			BWO-RYL-FF-ETF4	ELECTRONIC TRIP RELAY F FOR GROUP 7 FAILS	2.10E-05
21	0	7.10E-12	BWO-RPS-TM-CHA	CHANNEL A TEST AND MAINTENANCE	1.60E-02
			BWO-RYL-FF-TRB	TRIP RELAY B FAILS	2.10E-05
			BWO-RYL-FF-TRC	TRIP RELAY C FAILS	2.10E-05
22	0	7.10E-12	BWO-RPS-TM-CHA	CHANNEL A TEST AND MAINTENANCE	1.60E-02
			BWO-RYL-FF-TRB	TRIP RELAY B FAILS	2.10E-05
			BWO-RYL-FF-TRD	TRIP RELAY D FAILS	2.10E-05
23	0	7.10E-12	BWO-RPS-TM-CHA	CHANNEL A TEST AND MAINTENANCE	1.60E-02
			BWO-RYL-FF-TRC	TRIP RELAY C FAILS	2.10E-05
			BWO-RYL-FF-TRD	TRIP RELAY D FAILS	2.10E-05
24	0	3.10E-12	BWO-CPR-CF-P3OF4	CCF 3 OF 4 PRESSURE SENSORS/TRANSMITTERS	2.00E-06
			BWO-CTP-CF-T3OF4	CCF 3 OF 4 TEMPERATURE SENSORS/TRANSMITTERS	1.50E-06
			/BWO-RPS-TM-CHA	CHANNEL A TEST AND MAINTENANCE	9.80E-01
25	0	8.70E-13	BWO-BME-CF-TB3OF6-4G	CCF OF 2 OR MORE OF 6 RTBS	1.10E-06
			/BWO-RPS-TM-CHA	CHANNEL A TEST AND MAINTENANCE	9.80E-01
			BWO-RYL-CF-LR3OF8	CCF 3 OF 8 TRIP RELAYS CHANNELS C & D ONLY FOR ELECTRONIC TR	8.40E-07
26	0	7.00E-13	BWO-ROD-CF-RODS	ROD CCF, 20% OF RODS FAIL TO INSERT	8.40E-07
			/BWO-RPS-TM-CHA	CHANNEL A TEST AND MAINTENANCE	9.80E-01
			BWO-RYL-CF-LR3OF8	CCF 3 OF 8 TRIP RELAYS CHANNELS C & D ONLY FOR ELECTRONIC TR	8.40E-07
27	0	5.10E-13	BWO-CPR-CF-P2OF3TM	CCF 2 OF 3 PRESSURE SENSORS/TRANSMITTERS CH-A TM	6.40E-06
			BWO-CTP-CF-T2OF3TM	CCF 2 OF 3 TEMPERATURE SENSORS/TRANSMITTERS CH-A TM	4.90E-06
			BWO-RPS-TM-CHA	CHANNEL A TEST AND MAINTENANCE	1.60E-02
28	0	3.50E-13	BWO-BME-CF-TB3OF6-4G	CCF OF 2 OR MORE OF 6 RTBS	1.10E-06

Table F-9. (Continued)

Cut Set	Cut Set %	Cut Set Prob.	Basic Event a	Description	Prob.
			BWO-RYL-CF-TR3OF4	CCF 3 OF 4 TRIP RELAYS	3.30E-07
29	0	2.80E-13	BWO-ROD-CF-RODS	ROD CCF, 20% OF RODS FAIL TO INSERT	8.40E-07
			BWO-RYL-CF-TR3OF4	CCF 3 OF 4 TRIP RELAYS	3.30E-07
30	0	1.50E-13	BWO-BSN-CF-TB3OF6-4G	CCF OF 2 OR MORE OF 6 TBS SHUNT TRIP	3.50E-05
			BWO-BUV-CF-TB3OF6-4G	CCF OF 2 OR MORE OF 6 TBS UV DEVICES	1.20E-05
			BWO-RMA-FF-1OF20REG	1 REGULATING ROD OUT OF 20 FAILS TO INSERT	3.40E-04
31	0	1.10E-13	BWO-BME-FO-ACTB-A	AC TRIP BREAKER A LOCAL HARDWARE FAILURE	1.80E-05
			BWO-BME-FO-DCTB-C1	DC TRIP BREAKER C1 LOCAL HARDWARE FAILURE	1.80E-05
			BWO-RMA-FF-1OF20REG	1 REGULATING ROD OUT OF 20 FAILS TO INSERT	3.40E-04
32	0	1.10E-13	BWO-BME-FO-ACTB-A	AC TRIP BREAKER A LOCAL HARDWARE FAILURE	1.80E-05
			BWO-BME-FO-DCTB-C2	DC TRIP BREAKER C2 LOCAL HARDWARE FAILURE	1.80E-05
			BWO-RMA-FF-1OF20REG	1 REGULATING ROD OUT OF 20 FAILS TO INSERT	3.40E-04
33	0	1.10E-13	BWO-BME-FO-ACTB-B	AC TRIP BREAKER B LOCAL HARDWARE FAILURE	1.80E-05
			BWO-BME-FO-DCTB-D1	DC TRIP BREAKER D1 LOCAL HARDWARE FAILURE	1.80E-05
			BWO-RMA-FF-1OF20REG	1 REGULATING ROD OUT OF 20 FAILS TO INSERT	3.40E-04
34	0	1.10E-13	BWO-BME-FO-ACTB-B	AC TRIP BREAKER B LOCAL HARDWARE FAILURE	1.80E-05
			BWO-BME-FO-DCTB-D2	DC TRIP BREAKER D2 LOCAL HARDWARE FAILURE	1.80E-05
			BWO-RMA-FF-1OF20REG	1 REGULATING ROD OUT OF 20 FAILS TO INSERT	3.40E-04
35	0	6.10E-14	BWO-BME-CF-TB3OF6-4G	CCF OF 2 OR MORE OF 6 RTBS	1.10E-06
			BWO-RYL-CF-LR6OF12TM	CCF 6 OF 12 TRIP RELAYS (CH A IN T&M)	5.80E-08
36	0	4.90E-14	BWO-ROD-CF-RODS	ROD CCF, 20% OF RODS FAIL TO INSERT	8.40E-07
			BWO-RYL-CF-LR6OF12TM	CCF 6 OF 12 TRIP RELAYS (CH A IN T&M)	5.80E-08
37	0	4.20E-14	BWO-BME-CF-TB3OF6-4G	CCF OF 2 OR MORE OF 6 RTBS	1.10E-06
			BWO-RPS-TM-CHA	CHANNEL A TEST AND MAINTENANCE	1.60E-02
			BWO-RYL-CF-LR2OF6TM	CCF 2 OF 6 TRIP RELAYS CH C & D ONLY FOR ELEC. TRIP (CH-A TM)	2.50E-06
38	0	3.50E-14	BWO-BME-CF-TB3OF6-4G	CCF OF 2 OR MORE OF 6 RTBS	1.10E-06
			BWO-RYL-CF-LR9OF16	CCF SPECIFIC 9 OF 16 LOGIC RELAYS	3.30E-08
39	0	3.40E-14	BWO-ROD-CF-RODS	ROD CCF, 20% OF RODS FAIL TO INSERT	8.40E-07
			BWO-RPS-TM-CHA	CHANNEL A TEST AND MAINTENANCE	1.60E-02
			BWO-RYL-CF-LR2OF6TM	CCF 2 OF 6 TRIP RELAYS CH C & D ONLY FOR ELEC. TRIP (CH-A TM)	2.50E-06
40	0	2.80E-14	BWO-CBI-FF-PB	CH-B PRESSURE OUTPUT BISTABLE FAILS	2.90E-04
			BWO-CBI-FF-TB	CH-B TEMPERATURE OUTPUT BISTABLE FAILS	2.90E-04
			BWO-RPS-TM-CHA	CHANNEL A TEST AND MAINTENANCE	1.60E-02
			BWO-RYL-FF-TRC	TRIP RELAY C FAILS	2.10E-05
41	0	2.80E-14	BWO-CBI-FF-PB	CH-B PRESSURE OUTPUT BISTABLE FAILS	2.90E-04
			BWO-CBI-FF-TB	CH-B TEMPERATURE OUTPUT BISTABLE FAILS	2.90E-04
			BWO-RPS-TM-CHA	CHANNEL A TEST AND MAINTENANCE	1.60E-02
			BWO-RYL-FF-TRD	TRIP RELAY D FAILS	2.10E-05
42	0	2.80E-14	BWO-CBI-FF-PC	CH-C PRESSURE OUTPUT BISTABLE FAILS	2.90E-04
			BWO-CBI-FF-TC	CH-C TEMPERATURE OUTPUT BISTABLE FAILS	2.90E-04
			BWO-RPS-TM-CHA	CHANNEL A TEST AND MAINTENANCE	1.60E-02
			BWO-RYL-FF-TRB	TRIP RELAY B FAILS	2.10E-05
43	0	2.80E-14	BWO-CBI-FF-PC	CH-C PRESSURE OUTPUT BISTABLE FAILS	2.90E-04
			BWO-CBI-FF-TC	CH-C TEMPERATURE OUTPUT BISTABLE FAILS	2.90E-04
			BWO-RPS-TM-CHA	CHANNEL A TEST AND MAINTENANCE	1.60E-02
			BWO-RYL-FF-TRD	TRIP RELAY D FAILS	2.10E-05
44	0	2.80E-14	BWO-CBI-FF-PD	CH-D PRESSURE OUTPUT BISTABLE FAILS	2.90E-04
			BWO-CBI-FF-TD	CH-D TEMPERATURE OUTPUT BISTABLE FAILS	2.90E-04
			BWO-RPS-TM-CHA	CHANNEL A TEST AND MAINTENANCE	1.60E-02
			BWO-RYL-FF-TRB	TRIP RELAY B FAILS	2.10E-05
45	0	2.80E-14	BWO-CBI-FF-PD	CH-D PRESSURE OUTPUT BISTABLE FAILS	2.90E-04
			BWO-CBI-FF-TD	CH-D TEMPERATURE OUTPUT BISTABLE FAILS	2.90E-04
			BWO-RPS-TM-CHA	CHANNEL A TEST AND MAINTENANCE	1.60E-02
			BWO-RYL-FF-TRC	TRIP RELAY C FAILS	2.10E-05
46	0	2.80E-14	BWO-ROD-CF-RODS	ROD CCF, 20% OF RODS FAIL TO INSERT	8.40E-07
			BWO-RYL-CF-LR9OF16	CCF SPECIFIC 9 OF 16 LOGIC RELAYS	3.30E-08
47	0	1.60E-14	BWO-CBI-FF-TB	CH-B TEMPERATURE OUTPUT BISTABLE FAILS	2.90E-04
			BWO-CPR-FF-PB	CH-B PRESSURE SENSOR/TRANSMITTER FAILS	1.60E-04
			BWO-RPS-TM-CHA	CHANNEL A TEST AND MAINTENANCE	1.60E-02
			BWO-RYL-FF-TRC	TRIP RELAY C FAILS	2.10E-05
48	0	1.60E-14	BWO-CBI-FF-TB	CH-B TEMPERATURE OUTPUT BISTABLE FAILS	2.90E-04
			BWO-CPR-FF-PB	CH-B PRESSURE SENSOR/TRANSMITTER FAILS	1.60E-04
			BWO-RPS-TM-CHA	CHANNEL A TEST AND MAINTENANCE	1.60E-02
			BWO-RYL-FF-TRD	TRIP RELAY D FAILS	2.10E-05
49	0	1.60E-14	BWO-CBI-FF-TC	CH-C TEMPERATURE OUTPUT BISTABLE FAILS	2.90E-04

Appendix F

Table F-9. (Continued)

Cut Set	Cut Set %	Cut Set Prob.	Basic Event a	Description	Prob.
50	0	1.60E-14	BWO-CPR-FF-PC	CH-C PRESSURE SENSOR/TRANSMITTER FAILS	1.60E-04
			BWO-RPS-TM-CHA	CHANNEL A TEST AND MAINTENANCE	1.60E-02
			BWO-RYL-FF-TRB	TRIP RELAY B FAILS	2.10E-05
			BWO-CBI-FF-TC	CH-C TEMPERATURE OUTPUT BISTABLE FAILS	2.90E-04
			BWO-CPR-FF-PC	CH-C PRESSURE SENSOR/TRANSMITTER FAILS	1.60E-04
			BWO-RPS-TM-CHA	CHANNEL A TEST AND MAINTENANCE	1.60E-02
			BWO-RYL-FF-TRD	TRIP RELAY D FAILS	2.10E-05

- a. A / as the first character in a basic event name indicates a complemented event (Success = 1 - Failure). For example, the basic event for channel A in test and maintenance (T&M) is BWD-RPS-TM-CHA (Failure = 1.60E-02). Thus, the basic event name for channel A not in T&M is /BWD-RPS-TM-CHA (Success = 9.84E-01). The event description for complemented events remains the same as the description used for the failure event.

Table F-10. Importance measures sorted on Fussell-Vesely for Oconee (no manual scram).

Basic Event Name	Probability of Failure	Fussell-Vesely Importance	Risk Reduction Ratio	Risk Increase Ratio	Birnbaum Importance
BWO-CBI-CF-CBI6OF8	3.97E-07	5.01E-01	2.00E+00	1.26E+06	9.84E-01
BWO-RYL-CF-TR3OF4	3.29E-07	4.15E-01	1.71E+00	1.26E+06	9.84E-01
BWO-RYL-CF-LR9OF16	3.32E-08	4.19E-02	1.04E+00	1.26E+06	9.84E-01
BWO-RPS-TM-CHA	1.60E-02	2.55E-02	1.03E+00	2.57E+00	1.24E-06
BWO-RYL-CF-TR2OF3TM	1.07E-06	2.20E-02	1.02E+00	2.05E+04	1.60E-02
BWO-CBI-CF-CBI4OF6TM	8.70E-07	1.79E-02	1.02E+00	2.05E+04	1.60E-02
BWO-RYL-CF-LR6OF12TM	5.85E-08	1.20E-03	1.00E+00	2.05E+04	1.60E-02
BWO-RMA-FF-1OF20REG	3.40E-04	8.25E-04	1.00E+00	3.43E+00	1.89E-06
BWO-BME-CF-TB3OF6-4G	1.05E-06	6.29E-04	1.00E+00	6.00E+02	4.67E-04
BWO-ROD-CF-RODS	8.40E-07	5.03E-04	1.00E+00	6.00E+02	4.67E-04
BWO-RYL-FF-ETE4	2.10E-05	5.09E-05	1.00E+00	3.43E+00	1.89E-06
BWO-RYL-FF-ETE2	2.10E-05	5.09E-05	1.00E+00	3.43E+00	1.89E-06
BWO-RYL-FF-ETF2	2.10E-05	5.09E-05	1.00E+00	3.43E+00	1.89E-06
BWO-RYL-FF-ETF3	2.10E-05	5.09E-05	1.00E+00	3.43E+00	1.89E-06
BWO-RYL-FF-ETF4	2.10E-05	5.09E-05	1.00E+00	3.43E+00	1.89E-06
BWO-RYL-FF-ETE3	2.10E-05	5.09E-05	1.00E+00	3.43E+00	1.89E-06
BWO-RYL-FF-TRB	2.10E-05	1.83E-05	1.00E+00	1.87E+00	6.79E-07
BWO-RYL-FF-TRC	2.10E-05	1.83E-05	1.00E+00	1.87E+00	6.79E-07
BWO-RYL-FF-TRD	2.10E-05	1.83E-05	1.00E+00	1.87E+00	6.79E-07
BWO-CPR-CF-P3OF4	2.05E-06	3.93E-06	1.00E+00	2.92E+00	1.50E-06
BWO-CTP-CF-T3OF4	1.52E-06	3.93E-06	1.00E+00	3.59E+00	2.02E-06
BWO-RYL-CF-LR3OF8	8.43E-07	2.01E-06	1.00E+00	3.39E+00	1.86E-06
BWO-CPR-CF-P2OF3TM	6.38E-06	7.14E-07	1.00E+00	1.11E+00	8.73E-08
BWO-CTP-CF-T2OF3TM	4.95E-06	7.09E-07	1.00E+00	1.14E+00	1.12E-07
BWO-BME-FO-ACTB-B	1.80E-05	3.87E-07	1.00E+00	1.02E+00	1.68E-08
BWO-BME-FO-ACTB-A	1.80E-05	3.87E-07	1.00E+00	1.02E+00	1.68E-08
BWO-BSN-CF-TB3OF6-4G	3.54E-05	2.58E-07	1.00E+00	1.01E+00	5.69E-09
BWO-BUV-CF-TB3OF6-4G	1.22E-05	2.58E-07	1.00E+00	1.02E+00	1.65E-08
BWO-BME-FO-DCTB-D1	1.80E-05	1.93E-07	1.00E+00	1.01E+00	8.39E-09
BWO-BME-FO-DCTB-D2	1.80E-05	1.93E-07	1.00E+00	1.01E+00	8.39E-09
BWO-BME-FO-DCTB-C1	1.80E-05	1.93E-07	1.00E+00	1.01E+00	8.39E-09
BWO-BME-FO-DCTB-C2	1.80E-05	1.93E-07	1.00E+00	1.01E+00	8.39E-09
BWO-CBI-FF-TC	2.90E-04	1.44E-07	1.00E+00	1.00E+00	3.86E-10
BWO-CBI-FF-TD	2.90E-04	1.44E-07	1.00E+00	1.00E+00	3.86E-10
BWO-CBI-FF-TB	2.90E-04	1.44E-07	1.00E+00	1.00E+00	3.86E-10
BWO-CBI-FF-PC	2.90E-04	1.29E-07	1.00E+00	1.00E+00	3.47E-10
BWO-CBI-FF-PB	2.90E-04	1.29E-07	1.00E+00	1.00E+00	3.47E-10
BWO-CBI-FF-PD	2.90E-04	1.29E-07	1.00E+00	1.00E+00	3.47E-10
BWO-RYL-CF-LR2OF6TM	2.51E-06	9.74E-08	1.00E+00	1.04E+00	3.02E-08
BWO-CPR-FF-PC	1.60E-04	7.09E-08	1.00E+00	1.00E+00	3.47E-10
BWO-CPR-FF-PD	1.60E-04	7.09E-08	1.00E+00	1.00E+00	3.47E-10
BWO-CPR-FF-PB	1.60E-04	7.09E-08	1.00E+00	1.00E+00	3.47E-10
BWO-CTP-FF-TD	1.20E-04	5.92E-08	1.00E+00	1.00E+00	3.86E-10
BWO-CTP-FF-TC	1.20E-04	5.92E-08	1.00E+00	1.00E+00	3.86E-10
BWO-CTP-FF-TB	1.20E-04	5.92E-08	1.00E+00	1.00E+00	3.86E-10
BWO-RYL-FF-TRA	2.10E-05	3.50E-08	1.00E+00	1.00E+00	1.30E-09

Appendix F

Table F-11. Importance measures sorted on Risk Increase for Oconee (no manual scram).

Basic Event Name	Probability of Failure	Fussell-Vesely Importance	Risk Reduction Ratio	Risk Increase Ratio	Birnbaum Importance
BWO-CBI-CF-CBI6OF8	3.97E-07	5.01E-01	2.00E+00	1.26E+06	9.84E-01
BWO-RYL-CF-TR3OF4	3.29E-07	4.15E-01	1.71E+00	1.26E+06	9.84E-01
BWO-RYL-CF-LR9OF16	3.32E-08	4.19E-02	1.04E+00	1.26E+06	9.84E-01
BWO-RYL-CF-TR2OF3TM	1.07E-06	2.20E-02	1.02E+00	2.05E+04	1.60E-02
BWO-CBI-CF-CBI4OF6TM	8.70E-07	1.79E-02	1.02E+00	2.05E+04	1.60E-02
BWO-RYL-CF-LR6OF12TM	5.85E-08	1.20E-03	1.00E+00	2.05E+04	1.60E-02
BWO-BME-CF-TB3OF6-4G	1.05E-06	6.29E-04	1.00E+00	6.00E+02	4.67E-04
BWO-ROD-CF-RODS	8.40E-07	5.03E-04	1.00E+00	6.00E+02	4.67E-04
BWO-CTP-CF-T3OF4	1.52E-06	3.93E-06	1.00E+00	3.59E+00	2.02E-06
BWO-RMA-FF-1OF20REG	3.40E-04	8.25E-04	1.00E+00	3.43E+00	1.89E-06
BWO-RYL-FF-ETE4	2.10E-05	5.09E-05	1.00E+00	3.43E+00	1.89E-06
BWO-RYL-FF-ETE2	2.10E-05	5.09E-05	1.00E+00	3.43E+00	1.89E-06
BWO-RYL-FF-ETF2	2.10E-05	5.09E-05	1.00E+00	3.43E+00	1.89E-06
BWO-RYL-FF-ETF3	2.10E-05	5.09E-05	1.00E+00	3.43E+00	1.89E-06
BWO-RYL-FF-ETF4	2.10E-05	5.09E-05	1.00E+00	3.43E+00	1.89E-06
BWO-RYL-FF-ETE3	2.10E-05	5.09E-05	1.00E+00	3.43E+00	1.89E-06
BWO-RYL-CF-LR3OF8	8.43E-07	2.01E-06	1.00E+00	3.39E+00	1.86E-06
BWO-CPR-CF-P3OF4	2.05E-06	3.93E-06	1.00E+00	2.92E+00	1.50E-06
BWO-RPS-TM-CHA	1.60E-02	2.55E-02	1.03E+00	2.57E+00	1.24E-06
BWO-RYL-FF-TRB	2.10E-05	1.83E-05	1.00E+00	1.87E+00	6.79E-07
BWO-RYL-FF-TRC	2.10E-05	1.83E-05	1.00E+00	1.87E+00	6.79E-07
BWO-RYL-FF-TRD	2.10E-05	1.83E-05	1.00E+00	1.87E+00	6.79E-07
BWO-CTP-CF-T2OF3TM	4.95E-06	7.09E-07	1.00E+00	1.14E+00	1.12E-07
BWO-CPR-CF-P2OF3TM	6.38E-06	7.14E-07	1.00E+00	1.11E+00	8.73E-08
BWO-RYL-CF-LR2OF6TM	2.51E-06	9.74E-08	1.00E+00	1.04E+00	3.02E-08
BWO-BME-FO-ACTB-B	1.80E-05	3.87E-07	1.00E+00	1.02E+00	1.68E-08
BWO-BME-FO-ACTB-A	1.80E-05	3.87E-07	1.00E+00	1.02E+00	1.68E-08
BWO-BUV-CF-TB3OF6-4G	1.22E-05	2.58E-07	1.00E+00	1.02E+00	1.65E-08
BWO-BSN-CF-TB3OF6-4G	3.54E-05	2.58E-07	1.00E+00	1.01E+00	5.69E-09
BWO-BME-FO-DCTB-D1	1.80E-05	1.93E-07	1.00E+00	1.01E+00	8.39E-09
BWO-BME-FO-DCTB-D2	1.80E-05	1.93E-07	1.00E+00	1.01E+00	8.39E-09
BWO-BME-FO-DCTB-C1	1.80E-05	1.93E-07	1.00E+00	1.01E+00	8.39E-09
BWO-BME-FO-DCTB-C2	1.80E-05	1.93E-07	1.00E+00	1.01E+00	8.39E-09
BWO-CBI-FF-TC	2.90E-04	1.44E-07	1.00E+00	1.00E+00	3.86E-10
BWO-CBI-FF-TD	2.90E-04	1.44E-07	1.00E+00	1.00E+00	3.86E-10
BWO-CBI-FF-TB	2.90E-04	1.44E-07	1.00E+00	1.00E+00	3.86E-10
BWO-CBI-FF-PC	2.90E-04	1.29E-07	1.00E+00	1.00E+00	3.47E-10
BWO-CBI-FF-PB	2.90E-04	1.29E-07	1.00E+00	1.00E+00	3.47E-10
BWO-CBI-FF-PD	2.90E-04	1.29E-07	1.00E+00	1.00E+00	3.47E-10
BWO-CPR-FF-PC	1.60E-04	7.09E-08	1.00E+00	1.00E+00	3.47E-10
BWO-CPR-FF-PD	1.60E-04	7.09E-08	1.00E+00	1.00E+00	3.47E-10
BWO-CPR-FF-PB	1.60E-04	7.09E-08	1.00E+00	1.00E+00	3.47E-10
BWO-CTP-FF-TD	1.20E-04	5.92E-08	1.00E+00	1.00E+00	3.86E-10
BWO-CTP-FF-TC	1.20E-04	5.92E-08	1.00E+00	1.00E+00	3.86E-10
BWO-CTP-FF-TB	1.20E-04	5.92E-08	1.00E+00	1.00E+00	3.86E-10
BWO-RYL-FF-TRA	2.10E-05	3.50E-08	1.00E+00	1.00E+00	1.30E-09

Table F-12. Importance measures sorted on Birnbaum for Oconee (no manual scram).

Basic Event Name	Probability of Failure	Fussell-Vesely Importance	Risk Reduction Ratio	Risk Increase Ratio	Birnbaum Importance
BWO-CBI-CF-CBI6OF8	3.97E-07	5.01E-01	2.00E+00	1.26E+06	9.84E-01
BWO-RYL-CF-TR3OF4	3.29E-07	4.15E-01	1.71E+00	1.26E+06	9.84E-01
BWO-RYL-CF-LR9OF16	3.32E-08	4.19E-02	1.04E+00	1.26E+06	9.84E-01
BWO-RYL-CF-TR2OF3TM	1.07E-06	2.20E-02	1.02E+00	2.05E+04	1.60E-02
BWO-CBI-CF-CBI4OF6TM	8.70E-07	1.79E-02	1.02E+00	2.05E+04	1.60E-02
BWO-RYL-CF-LR6OF12TM	5.85E-08	1.20E-03	1.00E+00	2.05E+04	1.60E-02
BWO-BME-CF-TB3OF6-4G	1.05E-06	6.29E-04	1.00E+00	6.00E+02	4.67E-04
BWO-ROD-CF-RODS	8.40E-07	5.03E-04	1.00E+00	6.00E+02	4.67E-04
BWO-CTP-CF-T3OF4	1.52E-06	3.93E-06	1.00E+00	3.59E+00	2.02E-06
BWO-RMA-FF-1OF20REG	3.40E-04	8.25E-04	1.00E+00	3.43E+00	1.89E-06
BWO-RYL-FF-ETE4	2.10E-05	5.09E-05	1.00E+00	3.43E+00	1.89E-06
BWO-RYL-FF-ETE2	2.10E-05	5.09E-05	1.00E+00	3.43E+00	1.89E-06
BWO-RYL-FF-ETF2	2.10E-05	5.09E-05	1.00E+00	3.43E+00	1.89E-06
BWO-RYL-FF-ETF3	2.10E-05	5.09E-05	1.00E+00	3.43E+00	1.89E-06
BWO-RYL-FF-ETF4	2.10E-05	5.09E-05	1.00E+00	3.43E+00	1.89E-06
BWO-RYL-FF-ETE3	2.10E-05	5.09E-05	1.00E+00	3.43E+00	1.89E-06
BWO-RYL-CF-LR3OF8	8.43E-07	2.01E-06	1.00E+00	3.39E+00	1.86E-06
BWO-CPR-CF-P3OF4	2.05E-06	3.93E-06	1.00E+00	2.92E+00	1.50E-06
BWO-RPS-TM-CHA	1.60E-02	2.55E-02	1.03E+00	2.57E+00	1.24E-06
BWO-RYL-FF-TRB	2.10E-05	1.83E-05	1.00E+00	1.87E+00	6.79E-07
BWO-RYL-FF-TRC	2.10E-05	1.83E-05	1.00E+00	1.87E+00	6.79E-07
BWO-RYL-FF-TRD	2.10E-05	1.83E-05	1.00E+00	1.87E+00	6.79E-07
BWO-CTP-CF-T2OF3TM	4.95E-06	7.09E-07	1.00E+00	1.14E+00	1.12E-07
BWO-CPR-CF-P2OF3TM	6.38E-06	7.14E-07	1.00E+00	1.11E+00	8.73E-08
BWO-RYL-CF-LR2OF6TM	2.51E-06	9.74E-08	1.00E+00	1.04E+00	3.02E-08
BWO-BME-FO-ACTB-B	1.80E-05	3.87E-07	1.00E+00	1.02E+00	1.68E-08
BWO-BME-FO-ACTB-A	1.80E-05	3.87E-07	1.00E+00	1.02E+00	1.68E-08
BWO-BUV-CF-TB3OF6-4G	1.22E-05	2.58E-07	1.00E+00	1.02E+00	1.65E-08
BWO-BME-FO-DCTB-D1	1.80E-05	1.93E-07	1.00E+00	1.01E+00	8.39E-09
BWO-BME-FO-DCTB-D2	1.80E-05	1.93E-07	1.00E+00	1.01E+00	8.39E-09
BWO-BME-FO-DCTB-C1	1.80E-05	1.93E-07	1.00E+00	1.01E+00	8.39E-09
BWO-BME-FO-DCTB-C2	1.80E-05	1.93E-07	1.00E+00	1.01E+00	8.39E-09
BWO-BSN-CF-TB3OF6-4G	3.54E-05	2.58E-07	1.00E+00	1.01E+00	5.69E-09
BWO-RYL-FF-TRA	2.10E-05	3.50E-08	1.00E+00	1.00E+00	1.30E-09
BWO-CBI-FF-TC	2.90E-04	1.44E-07	1.00E+00	1.00E+00	3.86E-10
BWO-CBI-FF-TD	2.90E-04	1.44E-07	1.00E+00	1.00E+00	3.86E-10
BWO-CBI-FF-TB	2.90E-04	1.44E-07	1.00E+00	1.00E+00	3.86E-10
BWO-CTP-FF-TD	1.20E-04	5.92E-08	1.00E+00	1.00E+00	3.86E-10
BWO-CTP-FF-TC	1.20E-04	5.92E-08	1.00E+00	1.00E+00	3.86E-10
BWO-CTP-FF-TB	1.20E-04	5.92E-08	1.00E+00	1.00E+00	3.86E-10
BWO-CBI-FF-PC	2.90E-04	1.29E-07	1.00E+00	1.00E+00	3.47E-10
BWO-CBI-FF-PB	2.90E-04	1.29E-07	1.00E+00	1.00E+00	3.47E-10
BWO-CBI-FF-PD	2.90E-04	1.29E-07	1.00E+00	1.00E+00	3.47E-10
BWO-CPR-FF-PC	1.60E-04	7.09E-08	1.00E+00	1.00E+00	3.47E-10
BWO-CPR-FF-PD	1.60E-04	7.09E-08	1.00E+00	1.00E+00	3.47E-10
BWO-CPR-FF-PB	1.60E-04	7.09E-08	1.00E+00	1.00E+00	3.47E-10

Appendix F

Table F-13. RPS B&W Oconee top 50 cutsets (manual scram).

Cut Set	Cut Set %	Cut Set Prob.	Basic Event a	Description	Prob.
1	45	3.90E-09	BWO-CBI-CF-CBI6OF8 /BWO-RPS-TM-CHA	CCF SPECIFIC 6 OF 8 OUTPUT BISTABLES CHANNEL A TEST AND MAINTENANCE	4.00E-07 9.80E-01
2	37.3	3.20E-09	BWO-XHE-XE-SCRAM /BWO-RPS-TM-CHA	OPERATOR FAILS TO INITIATE MANUAL SCRAM CHANNEL A TEST AND MAINTENANCE	1.00E-02 9.80E-01
3	4.1	3.60E-10	BWO-RYL-CF-TR3OF4 BWO-XHE-XE-SCRAM	CCF 3 OF 4 TRIP RELAYS OPERATOR FAILS TO INITIATE MANUAL SCRAM	3.30E-07 1.00E-02
4	3.8	3.30E-10	BWO-BME-CF-TB3OF6-4G BWO-RMA-FF-1OF20REG	CCF OF 2 OR MORE OF 6 RTBS 1 REGULATING ROD OUT OF 20 FAILS TO INSERT	1.10E-06 3.40E-04
5	3.3	2.90E-10	BWO-RPS-TM-CHA BWO-RYL-CF-LR9OF16	CHANNEL A TEST AND MAINTENANCE CCF SPECIFIC 9 OF 16 LOGIC RELAYS	9.80E-01 3.30E-08
6	2	1.70E-10	BWO-XHE-XE-SCRAM BWO-RMA-FF-1OF20REG	OPERATOR FAILS TO INITIATE MANUAL SCRAM 1 REGULATING ROD OUT OF 20 FAILS TO INSERT	1.00E-02 3.40E-04
7	1.6	1.40E-10	BWO-ROD-CF-RODS BWO-RPS-TM-CHA	ROD CCF, 20% OF RODS FAIL TO INSERT CHANNEL A TEST AND MAINTENANCE	8.40E-07 1.60E-02
8	0.3	2.20E-11	BWO-RYL-CF-TR2OF3TM BWO-XHE-XE-SCRAM	CCF 2 OF 3 TRIP RELAYS CH-A TM OPERATOR FAILS TO INITIATE MANUAL SCRAM	1.10E-06 1.00E-02
9	0.3	2.20E-11	BWO-CBI-CF-CBI4OF6TM BWO-RPS-TM-CHA	CCF SPECIFIC 4 OF 6 OUTPUT BISTABLES CH-A TM CHANNEL A TEST AND MAINTENANCE	8.70E-07 1.60E-02
10	0.3	2.20E-11	BWO-XHE-XE-SCRAM BWO-BME-CF-TB3OF6-4G	OPERATOR FAILS TO INITIATE MANUAL SCRAM CCF OF 2 OR MORE OF 6 RTBS	1.00E-02 1.10E-06
11	0.3	2.20E-11	BWO-RYL-FF-ETE2 BWO-BME-CF-TB3OF6-4G	ELECTRONIC TRIP RELAY E FOR GROUP 5 FAILS CCF OF 2 OR MORE OF 6 RTBS	2.10E-05 1.10E-06
12	0.3	2.20E-11	BWO-RYL-FF-ETE3 BWO-BME-CF-TB3OF6-4G	ELECTRONIC TRIP RELAY E FOR GROUP 6 FAILS CCF OF 2 OR MORE OF 6 RTBS	2.10E-05 1.10E-06
13	0.3	2.20E-11	BWO-RYL-FF-ETE4 BWO-BME-CF-TB3OF6-4G	ELECTRONIC TRIP RELAY E FOR GROUP 7 FAILS CCF OF 2 OR MORE OF 6 RTBS	2.10E-05 1.10E-06
14	0.2	1.80E-11	BWO-BME-CF-TB3OF6-4G BWO-RYL-FF-ETF2	ELECTRONIC TRIP RELAY F FOR GROUP 5 FAILS CCF OF 2 OR MORE OF 6 RTBS	2.10E-05 1.10E-06
15	0.2	1.80E-11	BWO-RYL-FF-ETF3 BWO-BME-CF-TB3OF6-4G	ELECTRONIC TRIP RELAY F FOR GROUP 6 FAILS CCF OF 2 OR MORE OF 6 RTBS	2.10E-05 1.10E-06
16	0.2	1.80E-11	BWO-RYL-FF-ETF4 BWO-BME-CF-TB3OF6-4G	ELECTRONIC TRIP RELAY F FOR GROUP 7 FAILS CCF OF 2 OR MORE OF 6 RTBS	2.10E-05 1.10E-06
17	0.2	1.80E-11	BWO-ROD-CF-RODS BWO-RYL-FF-ETE2	ROD CCF, 20% OF RODS FAIL TO INSERT ELECTRONIC TRIP RELAY E FOR GROUP 5 FAILS	8.40E-07 2.10E-05
18	0.2	1.80E-11	BWO-RYL-FF-ETE3 BWO-ROD-CF-RODS	ROD CCF, 20% OF RODS FAIL TO INSERT ELECTRONIC TRIP RELAY E FOR GROUP 6 FAILS	8.40E-07 2.10E-05
19	0.2	1.80E-11	BWO-RYL-FF-ETE4 BWO-ROD-CF-RODS	ROD CCF, 20% OF RODS FAIL TO INSERT ELECTRONIC TRIP RELAY E FOR GROUP 7 FAILS	8.40E-07 2.10E-05
20	0.1	9.40E-12	BWO-ROD-CF-RODS BWO-RYL-FF-ETF2	ROD CCF, 20% OF RODS FAIL TO INSERT ELECTRONIC TRIP RELAY F FOR GROUP 5 FAILS	8.40E-07 2.10E-05
21	0	2.10E-12	BWO-RYL-FF-ETF3 BWO-ROD-CF-RODS	ROD CCF, 20% OF RODS FAIL TO INSERT ELECTRONIC TRIP RELAY F FOR GROUP 6 FAILS	8.40E-07 2.10E-05
22	0	1.80E-12	BWO-RYL-FF-ETF4 BWO-ROD-CF-RODS	ROD CCF, 20% OF RODS FAIL TO INSERT ELECTRONIC TRIP RELAY F FOR GROUP 7 FAILS	8.40E-07 2.10E-05
23	0	3.50E-13	BWO-ROD-CF-RODS BWO-RYL-FF-ETF2	ROD CCF, 20% OF RODS FAIL TO INSERT ELECTRONIC TRIP RELAY F FOR GROUP 5 FAILS	8.40E-07 2.10E-05
24	0	2.80E-13	BWO-RYL-FF-ETF3 BWO-ROD-CF-RODS	ROD CCF, 20% OF RODS FAIL TO INSERT ELECTRONIC TRIP RELAY F FOR GROUP 6 FAILS	8.40E-07 2.10E-05
25	0	1.80E-13	BWO-RYL-FF-ETF4 BWO-ROD-CF-RODS	ROD CCF, 20% OF RODS FAIL TO INSERT ELECTRONIC TRIP RELAY F FOR GROUP 7 FAILS	8.40E-07 2.10E-05
26	0	1.50E-13	BWO-ROD-CF-RODS BWO-RYL-FF-ETE2	ROD CCF, 20% OF RODS FAIL TO INSERT ELECTRONIC TRIP RELAY E FOR GROUP 5 FAILS	8.40E-07 2.10E-05
27	0	1.10E-13	BWO-RYL-FF-ETE3 BWO-ROD-CF-RODS	ROD CCF, 20% OF RODS FAIL TO INSERT ELECTRONIC TRIP RELAY E FOR GROUP 6 FAILS	8.40E-07 2.10E-05
			BWO-RYL-FF-ETE4 BWO-ROD-CF-RODS	ROD CCF, 20% OF RODS FAIL TO INSERT ELECTRONIC TRIP RELAY E FOR GROUP 7 FAILS	8.40E-07 2.10E-05
			BWO-RYL-FF-ETF2 BWO-ROD-CF-RODS	ROD CCF, 20% OF RODS FAIL TO INSERT ELECTRONIC TRIP RELAY F FOR GROUP 5 FAILS	8.40E-07 2.10E-05
			BWO-RYL-FF-ETF3 BWO-ROD-CF-RODS	ROD CCF, 20% OF RODS FAIL TO INSERT ELECTRONIC TRIP RELAY F FOR GROUP 6 FAILS	8.40E-07 2.10E-05
			BWO-RYL-FF-ETF4 BWO-ROD-CF-RODS	ROD CCF, 20% OF RODS FAIL TO INSERT ELECTRONIC TRIP RELAY F FOR GROUP 7 FAILS	8.40E-07 2.10E-05
			BWO-RPS-TM-CHA BWO-RYL-CF-LR6OF12TM	CHANNEL A TEST AND MAINTENANCE CCF 6 OF 12 TRIP RELAYS (CH A IN T&M)	1.00E-02 5.80E-08
			BWO-XHE-XE-SCRAM BWO-CBI-CF-CBI6OF8	OPERATOR FAILS TO INITIATE MANUAL SCRAM CCF SPECIFIC 6 OF 8 OUTPUT BISTABLES	1.00E-02 4.00E-07
			BWO-MSW-CF-2OF4 /BWO-RPS-TM-CHA	CCF OF 2 OF 4 MANUAL SCRAM SWITCH CHANNEL A TEST AND MAINTENANCE	5.40E-06 9.80E-01
			BWO-RYL-CF-TR3OF4 /BWO-RPS-TM-CHA	CCF OF 2 OF 4 MANUAL SCRAM SWITCH CHANNEL A TEST AND MAINTENANCE	5.40E-06 9.80E-01
			BWO-RYL-CF-TR3OF4 BWO-BME-CF-TB3OF6-4G	CCF 3 OF 4 TRIP RELAYS CCF OF 2 OR MORE OF 6 RTBS	3.30E-07 1.10E-06
			BWO-RYL-CF-TR3OF4 BWO-ROD-CF-RODS	CCF 3 OF 4 TRIP RELAYS ROD CCF, 20% OF RODS FAIL TO INSERT	3.30E-07 8.40E-07
			BWO-RYL-CF-TR3OF4 BWO-MSW-CF-2OF4	CCF 3 OF 4 TRIP RELAYS CCF OF 2 OF 4 MANUAL SCRAM SWITCH	3.30E-07 5.40E-06
			BWO-RYL-CF-LR9OF16 /BWO-RPS-TM-CHA	CCF SPECIFIC 9 OF 16 LOGIC RELAYS CHANNEL A TEST AND MAINTENANCE	3.30E-08 9.80E-01
			BWO-BSN-CF-TB3OF6-4G BWO-BUV-CF-TB3OF6-4G	CCF OF 2 OR MORE OF 6 TBS SHUNT TRIP CCF OF 2 OR MORE OF 6 TBS UV DEVICES	3.50E-05 1.20E-05
			BWO-RMA-FF-1OF20REG BWO-BME-FO-ACTB-A	1 REGULATING ROD OUT OF 20 FAILS TO INSERT AC TRIP BREAKER A LOCAL HARDWARE FAILURE	3.40E-04 1.80E-05
			BWO-BME-FO-DCTB-C1	DC TRIP BREAKER C1 LOCAL HARDWARE FAILURE	1.80E-05

Table F-13. (Continued)

Cut Set	Cut Set %	Cut Set Prob.	Basic Event a	Description	Prob.
28	0	1.10E-13	BWO-RMA-FF-1OF20REG	1 REGULATING ROD OUT OF 20 FAILS TO INSERT	3.40E-04
			BWO-BME-FO-ACTB-A	AC TRIP BREAKER A LOCAL HARDWARE FAILURE	1.80E-05
			BWO-BME-FO-DCTB-C2	DC TRIP BREAKER C2 LOCAL HARDWARE FAILURE	1.80E-05
29	0	1.10E-13	BWO-RMA-FF-1OF20REG	1 REGULATING ROD OUT OF 20 FAILS TO INSERT	3.40E-04
			BWO-BME-FO-ACTB-B	AC TRIP BREAKER B LOCAL HARDWARE FAILURE	1.80E-05
			BWO-BME-FO-DCTB-D1	DC TRIP BREAKER D1 LOCAL HARDWARE FAILURE	1.80E-05
30	0	1.10E-13	BWO-RMA-FF-1OF20REG	1 REGULATING ROD OUT OF 20 FAILS TO INSERT	3.40E-04
			BWO-BME-FO-ACTB-B	AC TRIP BREAKER B LOCAL HARDWARE FAILURE	1.80E-05
			BWO-BME-FO-DCTB-D2	DC TRIP BREAKER D2 LOCAL HARDWARE FAILURE	1.80E-05
31	0	9.30E-14	BWO-RMA-FF-1OF20REG	1 REGULATING ROD OUT OF 20 FAILS TO INSERT	3.40E-04
			BWO-MSW-CF-2OF4	CCF OF 2 OF 4 MANUAL SCRAM SWITCH	5.40E-06
			BWO-RPS-TM-CHA	CHANNEL A TEST AND MAINTENANCE	1.60E-02
32	0	7.60E-14	BWO-RYL-CF-TR2OF3TM	CCF 2 OF 3 TRIP RELAYS CH-A TM	1.10E-06
			BWO-CBI-CF-CB14OF6TM	CCF SPECIFIC 4 OF 6 OUTPUT BISTABLES CH-A TM	8.70E-07
			BWO-MSW-CF-2OF4	CCF OF 2 OF 4 MANUAL SCRAM SWITCH	5.40E-06
33	0	7.10E-14	BWO-RPS-TM-CHA	CHANNEL A TEST AND MAINTENANCE	1.60E-02
			BWO-RPS-TM-CHA	CHANNEL A TEST AND MAINTENANCE	1.60E-02
			BWO-RYL-FF-TRB	TRIP RELAY B FAILS	2.10E-05
34	0	7.10E-14	BWO-RYL-FF-TRC	TRIP RELAY C FAILS	2.10E-05
			BWO-XHE-XE-SCRAM	OPERATOR FAILS TO INITIATE MANUAL SCRAM	1.00E-02
			BWO-RPS-TM-CHA	CHANNEL A TEST AND MAINTENANCE	1.60E-02
35	0	7.10E-14	BWO-RYL-FF-TRB	TRIP RELAY B FAILS	2.10E-05
			BWO-RYL-FF-TRD	TRIP RELAY D FAILS	2.10E-05
			BWO-XHE-XE-SCRAM	OPERATOR FAILS TO INITIATE MANUAL SCRAM	1.00E-02
36	0	6.10E-14	BWO-RPS-TM-CHA	CHANNEL A TEST AND MAINTENANCE	1.60E-02
			BWO-RYL-FF-TRC	TRIP RELAY C FAILS	2.10E-05
			BWO-RYL-FF-TRD	TRIP RELAY D FAILS	2.10E-05
37	0	4.90E-14	BWO-XHE-XE-SCRAM	OPERATOR FAILS TO INITIATE MANUAL SCRAM	1.00E-02
			BWO-RPS-TM-CHA	CHANNEL A TEST AND MAINTENANCE	1.60E-02
			BWO-RYL-FF-TRC	TRIP RELAY C FAILS	2.10E-05
38	0	3.50E-14	BWO-RYL-FF-TRD	TRIP RELAY D FAILS	2.10E-05
			BWO-XHE-XE-SCRAM	OPERATOR FAILS TO INITIATE MANUAL SCRAM	1.00E-02
			BWO-RPS-TM-CHA	CHANNEL A TEST AND MAINTENANCE	1.60E-02
39	0	3.10E-14	BWO-RYL-FF-TRC	TRIP RELAY C FAILS	2.10E-05
			BWO-RYL-FF-TRD	TRIP RELAY D FAILS	2.10E-05
			BWO-XHE-XE-SCRAM	OPERATOR FAILS TO INITIATE MANUAL SCRAM	1.00E-02
40	0	2.80E-14	BWO-CPR-CF-P3OF4	CCF 3 OF 4 PRESSURE SENSORS/TRANSMITTERS	2.00E-06
			BWO-CTP-CF-T3OF4	CCF 3 OF 4 TEMPERATURE SENSORS/TRANSMITTERS	1.50E-06
			/BWO-RPS-TM-CHA	CHANNEL A TEST AND MAINTENANCE	9.80E-01
41	0	9.10E-15	BWO-XHE-XE-SCRAM	OPERATOR FAILS TO INITIATE MANUAL SCRAM	1.00E-02
			BWO-ROD-CF-RODS	ROD CCF, 20% OF RODS FAIL TO INSERT	8.40E-07
			BWO-RYL-FF-ET2	CCF SPECIFIC 9 OF 16 LOGIC RELAYS	3.30E-08
42	0	9.10E-15	BWO-RYL-FF-ET3	CCF SPECIFIC 9 OF 16 LOGIC RELAYS	3.30E-08
			BWO-BSN-CF-TB3OF6-4G	CCF OF 2 OR MORE OF 6 TBS SHUNT TRIP	3.50E-05
			BWO-BUV-CF-TB3OF6-4G	CCF OF 2 OR MORE OF 6 TBS UV DEVICES	1.20E-05
43	0	9.10E-15	BWO-RYL-FF-ET4	ELECTRONIC TRIP RELAY E FOR GROUP 5 FAILS	2.10E-05
			BWO-BSN-CF-TB3OF6-4G	CCF OF 2 OR MORE OF 6 TBS SHUNT TRIP	3.50E-05
			BWO-BUV-CF-TB3OF6-4G	CCF OF 2 OR MORE OF 6 TBS UV DEVICES	1.20E-05
44	0	9.10E-15	BWO-RYL-FF-ET5	ELECTRONIC TRIP RELAY E FOR GROUP 6 FAILS	2.10E-05
			BWO-BSN-CF-TB3OF6-4G	CCF OF 2 OR MORE OF 6 TBS SHUNT TRIP	3.50E-05
			BWO-BUV-CF-TB3OF6-4G	CCF OF 2 OR MORE OF 6 TBS UV DEVICES	1.20E-05
45	0	9.10E-15	BWO-RYL-FF-ET6	ELECTRONIC TRIP RELAY E FOR GROUP 7 FAILS	2.10E-05
			BWO-BSN-CF-TB3OF6-4G	CCF OF 2 OR MORE OF 6 TBS SHUNT TRIP	3.50E-05
			BWO-BUV-CF-TB3OF6-4G	CCF OF 2 OR MORE OF 6 TBS UV DEVICES	1.20E-05
46	0	9.10E-15	BWO-RYL-FF-ET7	ELECTRONIC TRIP RELAY E FOR GROUP 8 FAILS	2.10E-05
			BWO-BSN-CF-TB3OF6-4G	CCF OF 2 OR MORE OF 6 TBS SHUNT TRIP	3.50E-05
			BWO-BUV-CF-TB3OF6-4G	CCF OF 2 OR MORE OF 6 TBS UV DEVICES	1.20E-05
47	0	8.70E-15	BWO-RYL-FF-ET8	ELECTRONIC TRIP RELAY E FOR GROUP 9 FAILS	2.10E-05
			BWO-BSN-CF-TB3OF6-4G	CCF OF 2 OR MORE OF 6 TBS SHUNT TRIP	3.50E-05
			BWO-BUV-CF-TB3OF6-4G	CCF OF 2 OR MORE OF 6 TBS UV DEVICES	1.20E-05
48	0	7.00E-15	BWO-RYL-FF-ET9	ELECTRONIC TRIP RELAY E FOR GROUP 10 FAILS	2.10E-05
			BWO-BSN-CF-TB3OF6-4G	CCF OF 2 OR MORE OF 6 TBS SHUNT TRIP	3.50E-05
			BWO-BUV-CF-TB3OF6-4G	CCF OF 2 OR MORE OF 6 TBS UV DEVICES	1.20E-05

Appendix F

Table F-13. (Continued)

Cut Set	Cut Set %	Cut Set Prob.	Basic Event a	Description	Prob.
49	0	6.80E-15	BWO-XHE-XE-SCRAM	OPERATOR FAILS TO INITIATE MANUAL SCRAM	1.00E-02
			BWO-BME-FO-ACTB-A	AC TRIP BREAKER A LOCAL HARDWARE FAILURE	1.80E-05
			BWO-BME-FO-DCTB-C1	DC TRIP BREAKER C1 LOCAL HARDWARE FAILURE	1.80E-05
50	0	6.80E-15	BWO-RYL-FF-ETE2	ELECTRONIC TRIP RELAY E FOR GROUP 5 FAILS	2.10E-05
			BWO-BME-FO-ACTB-A	AC TRIP BREAKER A LOCAL HARDWARE FAILURE	1.80E-05
			BWO-BME-FO-DCTB-C1	DC TRIP BREAKER C1 LOCAL HARDWARE FAILURE	1.80E-05
			BWO-RYL-FF-ETE3	ELECTRONIC TRIP RELAY E FOR GROUP 6 FAILS	2.10E-05

- a. A / as the first character in a basic event name indicates a complemented event (Success = 1 - Failure). For example, the basic event for channel A in test and maintenance (T&M) is BWD-RPS-TM-CHA (Failure = 1.60E-02). Thus, the basic event name for channel A not in T&M is /BWD-RPS-TM-CHA (Success = 9.84E-01). The event description for complemented events remains the same as the description used for the failure event.

Table F-14. Importance measures sorted on Fussell-Vesely for Oconee (manual scram).

Basic Event Name	Probability of Failure	Fussell-Vesely Importance	Risk Reduction Ratio	Risk Increase Ratio	Birnbaum Importance
BWO-XHE-XE-SCRAM	1.00E-02	8.98E-01	9.79E+00	8.99E+01	7.79E-07
BWO-CBI-CF-CBI6OF8	3.97E-07	4.51E-01	1.82E+00	1.14E+06	9.85E-03
BWO-RYL-CF-TR3OF4	3.29E-07	3.73E-01	1.60E+00	1.14E+06	9.85E-03
BWO-RMA-FF-1OF20REG	3.40E-04	7.41E-02	1.08E+00	2.19E+02	1.89E-06
BWO-BME-CF-TB3OF6-4G	1.05E-06	5.64E-02	1.06E+00	5.38E+04	4.66E-04
BWO-ROD-CF-RODS	8.40E-07	4.52E-02	1.05E+00	5.38E+04	4.66E-04
BWO-RYL-CF-LR9OF16	3.32E-08	3.77E-02	1.04E+00	1.14E+06	9.85E-03
BWO-RPS-TM-CHA	1.60E-02	2.29E-02	1.02E+00	2.41E+00	1.24E-08
BWO-RYL-CF-TR2OF3TM	1.07E-06	1.97E-02	1.02E+00	1.85E+04	1.60E-04
BWO-CBI-CF-CBI4OF6TM	8.70E-07	1.61E-02	1.02E+00	1.85E+04	1.60E-04
BWO-RYL-FF-ETE2	2.10E-05	4.58E-03	1.01E+00	2.19E+02	1.89E-06
BWO-RYL-FF-ETE3	2.10E-05	4.58E-03	1.01E+00	2.19E+02	1.89E-06
BWO-RYL-FF-ETE4	2.10E-05	4.58E-03	1.01E+00	2.19E+02	1.89E-06
BWO-RYL-FF-ETF2	2.10E-05	4.58E-03	1.01E+00	2.19E+02	1.89E-06
BWO-RYL-FF-ETF3	2.10E-05	4.58E-03	1.01E+00	2.19E+02	1.89E-06
BWO-RYL-FF-ETF4	2.10E-05	4.58E-03	1.01E+00	2.19E+02	1.89E-06
BWO-RYL-CF-LR6OF12TM	5.85E-08	1.09E-03	1.00E+00	1.87E+04	1.62E-04
BWO-MSW-CF-2OF4	5.43E-06	4.88E-04	1.00E+00	9.08E+01	7.79E-07
BWO-BME-FO-ACTB-B	1.80E-05	3.48E-05	1.00E+00	2.93E+00	1.68E-08
BWO-BME-FO-ACTB-A	1.80E-05	3.48E-05	1.00E+00	2.93E+00	1.68E-08
BWO-BUV-CF-TB3OF6-4G	1.22E-05	2.32E-05	1.00E+00	2.90E+00	1.65E-08
BWO-BSN-CF-TB3OF6-4G	3.54E-05	2.32E-05	1.00E+00	1.66E+00	5.69E-09
BWO-BME-FO-DCTB-D1	1.80E-05	1.74E-05	1.00E+00	1.97E+00	8.39E-09
BWO-BME-FO-DCTB-C2	1.80E-05	1.74E-05	1.00E+00	1.97E+00	8.39E-09
BWO-BME-FO-DCTB-C1	1.80E-05	1.74E-05	1.00E+00	1.97E+00	8.39E-09
BWO-BME-FO-DCTB-D2	1.80E-05	1.74E-05	1.00E+00	1.97E+00	8.39E-09
BWO-RYL-FF-TRD	2.10E-05	1.63E-05	1.00E+00	1.77E+00	6.72E-09
BWO-RYL-FF-TRC	2.10E-05	1.63E-05	1.00E+00	1.77E+00	6.72E-09
BWO-RYL-FF-TRB	2.10E-05	1.63E-05	1.00E+00	1.77E+00	6.72E-09
BWO-CTP-CF-T3OF4	1.52E-06	3.53E-06	1.00E+00	3.33E+00	2.02E-08
BWO-CPR-CF-P3OF4	2.05E-06	3.53E-06	1.00E+00	2.72E+00	1.50E-08
BWO-RYL-CF-LR3OF8	8.43E-07	1.80E-06	1.00E+00	3.14E+00	1.86E-08
BWO-MSW-FF-MT3	1.30E-04	1.38E-06	1.00E+00	1.01E+00	9.29E-11
BWO-MSW-FF-MT1	1.30E-04	1.38E-06	1.00E+00	1.01E+00	9.29E-11
BWO-MSW-FF-MT2	1.30E-04	1.38E-06	1.00E+00	1.01E+00	9.29E-11
BWO-MSW-FF-MT4	1.30E-04	1.38E-06	1.00E+00	1.01E+00	9.29E-11
BWO-CPR-CF-P2OF3TM	6.38E-06	5.89E-07	1.00E+00	1.09E+00	7.92E-10
BWO-CTP-CF-T2OF3TM	4.95E-06	5.89E-07	1.00E+00	1.12E+00	1.02E-09

Appendix F

Table F-15. Importance measures sorted on Risk Increase for Oconee (manual scram).

Basic Event Name	Probability of Failure	Fussell-Vesely Importance	Risk Reduction Ratio	Risk Increase Ratio	Birnbaum Importance
BWO-CBI-CF-CBI6OF8	3.97E-07	4.51E-01	1.82E+00	1.14E+06	9.85E-03
BWO-RYL-CF-TR3OF4	3.29E-07	3.73E-01	1.60E+00	1.14E+06	9.85E-03
BWO-RYL-CF-LR9OF16	3.32E-08	3.77E-02	1.04E+00	1.14E+06	9.85E-03
BWO-BME-CF-TB3OF6-4G	1.05E-06	5.64E-02	1.06E+00	5.38E+04	4.66E-04
BWO-ROD-CF-RODS	8.40E-07	4.52E-02	1.05E+00	5.38E+04	4.66E-04
BWO-RYL-CF-LR6OF12TM	5.85E-08	1.09E-03	1.00E+00	1.87E+04	1.62E-04
BWO-RYL-CF-TR2OF3TM	1.07E-06	1.97E-02	1.02E+00	1.85E+04	1.60E-04
BWO-CBI-CF-CBI4OF6TM	8.70E-07	1.61E-02	1.02E+00	1.85E+04	1.60E-04
BWO-RMA-FF-1OF20REG	3.40E-04	7.41E-02	1.08E+00	2.19E+02	1.89E-06
BWO-RYL-FF-ETE2	2.10E-05	4.58E-03	1.01E+00	2.19E+02	1.89E-06
BWO-RYL-FF-ETE3	2.10E-05	4.58E-03	1.01E+00	2.19E+02	1.89E-06
BWO-RYL-FF-ETE4	2.10E-05	4.58E-03	1.01E+00	2.19E+02	1.89E-06
BWO-RYL-FF-ETF2	2.10E-05	4.58E-03	1.01E+00	2.19E+02	1.89E-06
BWO-RYL-FF-ETF3	2.10E-05	4.58E-03	1.01E+00	2.19E+02	1.89E-06
BWO-RYL-FF-ETF4	2.10E-05	4.58E-03	1.01E+00	2.19E+02	1.89E-06
BWO-MSW-CF-2OF4	5.43E-06	4.88E-04	1.00E+00	9.08E+01	7.79E-07
BWO-XHE-XE-SCRAM	1.00E-02	8.98E-01	9.79E+00	8.99E+01	7.79E-07
BWO-CTP-CF-T3OF4	1.52E-06	3.53E-06	1.00E+00	3.33E+00	2.02E-08
BWO-RYL-CF-LR3OF8	8.43E-07	1.80E-06	1.00E+00	3.14E+00	1.86E-08
BWO-BME-FO-ACTB-B	1.80E-05	3.48E-05	1.00E+00	2.93E+00	1.68E-08
BWO-BME-FO-ACTB-A	1.80E-05	3.48E-05	1.00E+00	2.93E+00	1.68E-08
BWO-BUV-CF-TB3OF6-4G	1.22E-05	2.32E-05	1.00E+00	2.90E+00	1.65E-08
BWO-CPR-CF-P3OF4	2.05E-06	3.53E-06	1.00E+00	2.72E+00	1.50E-08
BWO-RPS-TM-CHA	1.60E-02	2.29E-02	1.02E+00	2.41E+00	1.24E-08
BWO-BME-FO-DCTB-D1	1.80E-05	1.74E-05	1.00E+00	1.97E+00	8.39E-09
BWO-BME-FO-DCTB-C2	1.80E-05	1.74E-05	1.00E+00	1.97E+00	8.39E-09
BWO-BME-FO-DCTB-C1	1.80E-05	1.74E-05	1.00E+00	1.97E+00	8.39E-09
BWO-BME-FO-DCTB-D2	1.80E-05	1.74E-05	1.00E+00	1.97E+00	8.39E-09
BWO-RYL-FF-TRD	2.10E-05	1.63E-05	1.00E+00	1.77E+00	6.72E-09
BWO-RYL-FF-TRC	2.10E-05	1.63E-05	1.00E+00	1.77E+00	6.72E-09
BWO-RYL-FF-TRB	2.10E-05	1.63E-05	1.00E+00	1.77E+00	6.72E-09
BWO-BSN-CF-TB3OF6-4G	3.54E-05	2.32E-05	1.00E+00	1.66E+00	5.69E-09
BWO-CTP-CF-T2OF3TM	4.95E-06	5.89E-07	1.00E+00	1.12E+00	1.02E-09
BWO-CPR-CF-P2OF3TM	6.38E-06	5.89E-07	1.00E+00	1.09E+00	7.92E-10
BWO-MSW-FF-MT3	1.30E-04	1.38E-06	1.00E+00	1.01E+00	9.29E-11
BWO-MSW-FF-MT1	1.30E-04	1.38E-06	1.00E+00	1.01E+00	9.29E-11
BWO-MSW-FF-MT2	1.30E-04	1.38E-06	1.00E+00	1.01E+00	9.29E-11
BWO-MSW-FF-MT4	1.30E-04	1.38E-06	1.00E+00	1.01E+00	9.29E-11

Table F-16. Importance measures sorted on Birnbaum for Oconee (manual scram).

Basic Event Name	Probability of Failure	Fussell-Vesely Importance	Risk Reduction Ratio	Risk Increase Ratio	Birnbaum Importance
BWO-CBI-CF-CBI6OF8	3.97E-07	4.51E-01	1.82E+00	1.14E+06	9.85E-03
BWO-RYL-CF-TR3OF4	3.29E-07	3.73E-01	1.60E+00	1.14E+06	9.85E-03
BWO-RYL-CF-LR9OF16	3.32E-08	3.77E-02	1.04E+00	1.14E+06	9.85E-03
BWO-BME-CF-TB3OF6-4G	1.05E-06	5.64E-02	1.06E+00	5.38E+04	4.66E-04
BWO-ROD-CF-RODS	8.40E-07	4.52E-02	1.05E+00	5.38E+04	4.66E-04
BWO-RYL-CF-LR6OF12TM	5.85E-08	1.09E-03	1.00E+00	1.87E+04	1.62E-04
BWO-RYL-CF-TR2OF3TM	1.07E-06	1.97E-02	1.02E+00	1.85E+04	1.60E-04
BWO-CBI-CF-CBI4OF6TM	8.70E-07	1.61E-02	1.02E+00	1.85E+04	1.60E-04
BWO-RMA-FF-1OF20REG	3.40E-04	7.41E-02	1.08E+00	2.19E+02	1.89E-06
BWO-RYL-FF-ETE2	2.10E-05	4.58E-03	1.01E+00	2.19E+02	1.89E-06
BWO-RYL-FF-ETE3	2.10E-05	4.58E-03	1.01E+00	2.19E+02	1.89E-06
BWO-RYL-FF-ETE4	2.10E-05	4.58E-03	1.01E+00	2.19E+02	1.89E-06
BWO-RYL-FF-ETF2	2.10E-05	4.58E-03	1.01E+00	2.19E+02	1.89E-06
BWO-RYL-FF-ETF3	2.10E-05	4.58E-03	1.01E+00	2.19E+02	1.89E-06
BWO-RYL-FF-ETF4	2.10E-05	4.58E-03	1.01E+00	2.19E+02	1.89E-06
BWO-XHE-XE-SCRAM	1.00E-02	8.98E-01	9.79E+00	8.99E+01	7.79E-07
BWO-MSW-CF-2OF4	5.43E-06	4.88E-04	1.00E+00	9.08E+01	7.79E-07
BWO-CTP-CF-T3OF4	1.52E-06	3.53E-06	1.00E+00	3.33E+00	2.02E-08
BWO-RYL-CF-LR3OF8	8.43E-07	1.80E-06	1.00E+00	3.14E+00	1.86E-08
BWO-BME-FO-ACTB-B	1.80E-05	3.48E-05	1.00E+00	2.93E+00	1.68E-08
BWO-BME-FO-ACTB-A	1.80E-05	3.48E-05	1.00E+00	2.93E+00	1.68E-08
BWO-BUV-CF-TB3OF6-4G	1.22E-05	2.32E-05	1.00E+00	2.90E+00	1.65E-08
BWO-CPR-CF-P3OF4	2.05E-06	3.53E-06	1.00E+00	2.72E+00	1.50E-08
BWO-RPS-TM-CHA	1.60E-02	2.29E-02	1.02E+00	2.41E+00	1.24E-08
BWO-BME-FO-DCTB-D1	1.80E-05	1.74E-05	1.00E+00	1.97E+00	8.39E-09
BWO-BME-FO-DCTB-C2	1.80E-05	1.74E-05	1.00E+00	1.97E+00	8.39E-09
BWO-BME-FO-DCTB-C1	1.80E-05	1.74E-05	1.00E+00	1.97E+00	8.39E-09
BWO-BME-FO-DCTB-D2	1.80E-05	1.74E-05	1.00E+00	1.97E+00	8.39E-09
BWO-RYL-FF-TRD	2.10E-05	1.63E-05	1.00E+00	1.77E+00	6.72E-09
BWO-RYL-FF-TRC	2.10E-05	1.63E-05	1.00E+00	1.77E+00	6.72E-09
BWO-RYL-FF-TRB	2.10E-05	1.63E-05	1.00E+00	1.77E+00	6.72E-09
BWO-BSN-CF-TB3OF6-4G	3.54E-05	2.32E-05	1.00E+00	1.66E+00	5.69E-09
BWO-CTP-CF-T2OF3TM	4.95E-06	5.89E-07	1.00E+00	1.12E+00	1.02E-09
BWO-CPR-CF-P2OF3TM	6.38E-06	5.89E-07	1.00E+00	1.09E+00	7.92E-10
BWO-MSW-FF-MT3	1.30E-04	1.38E-06	1.00E+00	1.01E+00	9.29E-11
BWO-MSW-FF-MT1	1.30E-04	1.38E-06	1.00E+00	1.01E+00	9.29E-11
BWO-MSW-FF-MT2	1.30E-04	1.38E-06	1.00E+00	1.01E+00	9.29E-11
BWO-MSW-FF-MT4	1.30E-04	1.38E-06	1.00E+00	1.01E+00	9.29E-11

Appendix G

Sensitivity Analysis

G SENSITIVITY ANALYSIS

Sensitivity analyses of the Babcock & Wilcox Reactor Protection System (RPS) fault tree model and quantification were performed in the area of success criteria. Three sensitivities were analyzed: The sensitivity from using two trip parameters versus three trip parameters, the sensitivity to the rod failure criteria, and the sensitivity to the addition of the diverse electronic trip.

G-1 Three Trip Parameter Sensitivity

Two trip signals were included in the RPS fault tree model: hot leg temperature and pressurizer pressure. If three trip signals were included in the model, then two of the CCF events dominating the RPS channel unavailability would be affected. Table G-1 shows the revised CCF basic events for three-trip parameters contribution and their point estimates. In both cases, the events would change from specific six of eight failures to specific nine of twelve failures. Given these changes, in the no operator action case, the RPS unavailability drops from $7.8\text{E-}7$ for Oconee to approximately $5.1\text{E-}7$ (34 percent decrease). The RPS unavailability also drops from $1.6\text{E-}6$ for Davis-Besse to approximately $1.4\text{E-}6$ (16 percent decrease).

Table G-1. Three-trip parameter basic events.

Three Trip Parameter Basic Events	CCF Basic Event Probability
BWO(D)-CBI-CF-CBI9OF12	1.4E-7
BWO(D)-CBI-CF-CBI6OF9TM	2.5E-7

Figure G-1 shows the overall point estimate of unavailability comparison between two and three trip parameters with no operator action. Figure G-2 shows a similar distribution, but for the results including operator action. When operator action is factored in, the channel contribution decreases significantly, leaving no detectable difference between the models.

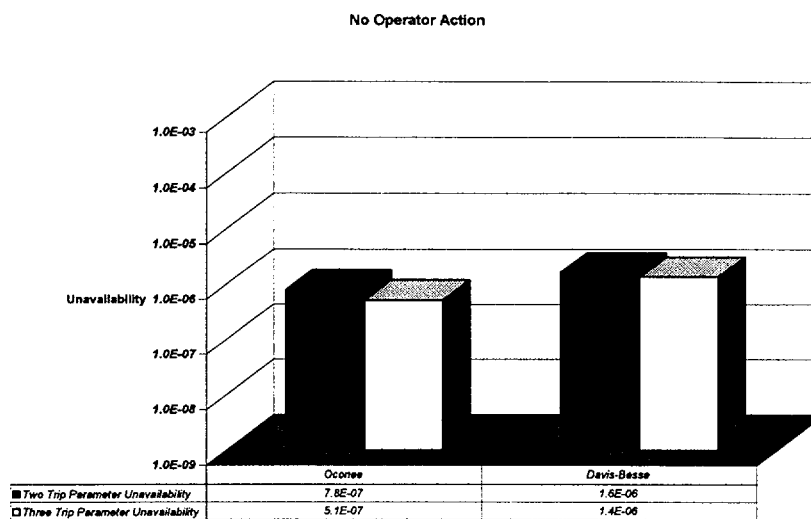


Figure G-1. Sensitivity comparison with no operator action.

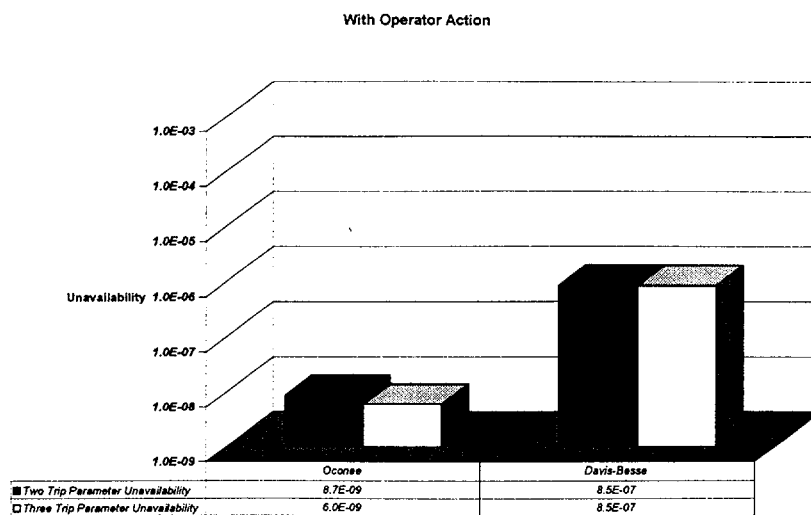


Figure G-2. Sensitivity with operator action.

In all cases, the bistable CCF events change from specific six of eight failures to specific nine of twelve failures. Given these changes, the RPS unavailability is shown in Table G-2 shows the segment percent contributions from the two trip parameter so that it can be compared to the segment percent contribution from the three-trip parameter model. In both cases, the channel segment decreases its contribution by approximately 50 percent.

Table G-2. Three trip parameter results and comparison to two trip parameters.

RPS Segment	Unavailability (Point Estimate) with No Credit for Manual Scram by Operator			Unavailability (Point Estimate) with Credit for Manual Scram by Operator		
	Two Trip Parameter Percent	Three Trip Parameter Percent	Three Trip Parameter Unavailability	Two Trip Parameter Percent	Three Trip Parameter Percent	Three Trip Parameter Unavailability
Oconee RPS Model						
Channel	51.9%	27.2%	1.4E-07	46.5%	23.1%	1.4E-09
Trip Modules	48.0%	72.8%	3.7E-07	42.9%	61.8%	3.7E-09
Trip Breakers/Diverse	0.0%	0.0%	0.0E+00	7.2%	10.3%	6.2E-10
Trip						
Rods	0.0%	0.1%	2.9E-10	3.3%	4.8%	2.9E-10
Total Oconee RPS	100.0%	100.0%	5.1E-07	100.0%	100.0%	6.0E-09
Davis-Besse RPS Model						
Channel	25.1%	10.3%	1.4E-07	0.5%	0.2%	1.4E-09
Trip Modules	23.0%	27.5%	3.7E-07	0.4%	0.4%	3.7E-09
Trip Breakers/Diverse	0.0%	0.0%	5.5E-11	0.0%	0.0%	3.0E-11
Trip						
Rods	52.0%	62.2%	8.4E-07	99.1%	99.4%	8.4E-07
Total Davis-Besse RPS	100.0%	100.0%	1.4E-06	100.0%	100.0%	8.5E-07

G-2 Rod Failure Criterion Sensitivity

The Babcock & Wilcox RPS fault tree includes an event that represents the CCF of the rods to insert, given that the trip breaker(s) have opened. The components included in this failure are the rods and the control rod drive mechanisms (CRDs). One BE has been assigned to the supercomponent, RMA. Babcock & Wilcox cores contain approximately 41 safety rods. This section describes the sensitivity of the BE probability and the RPS unavailability to the assumed failure criterion.

G-2.1 Rod Failure Criteria

The probability of the failure of sufficient rods to insert and shut down the reactor due to ROD or CRD common-cause failure is expected to be very small. This event has never occurred in the operating history of commercial PWR nuclear power plants. The calculated common-cause failure probability depends on the number of rods required to insert. For most transients, the insertion of a few rods is sufficient to shut down the reactor. For others, it requires more rods to insert. In rare cases, insertion of all of the rods will not guarantee successful shut down of the reactor.

From 1984 through 1998, only three possible failures to insert PWR ROD and CRD common-cause events were observed. In the first event, two rods were observed to have clad cracking and guide wear. The other 46 rods were assigned a degradation value of 0.1 due to the design flaw nature of the fault. In another event, two control rod drives out of 48 exhibited faulty firing circuits. In the last event, the drive screw threads were galled. Thus, the operating experience is very sparse.

G-2.2 Rod CCF BE Failure Probability Sensitivity Results

The failure criterion assumed for this study is that eight or more safety group rods out of 41 fail to insert fully into the core upon demand. The Rod CCF Basic Event probabilities were calculated for 20, 30, 40, 50, 60, 70, and 80 percent failure criteria, and are shown in Figure G-3. The Davis-Besse and Oconee RPS models were evaluated, using the stated Rod CCF criteria, and the results are shown in Figure G-3. The choice of eight or more rods failing to insert results in a rod unavailability contribution

of <0.1 to 52 percent (no operator action). The Oconee design is completely insensitive to the rod failure criteria. This is because of the diverse trip modeled, which provides another success path. The Davis-Besse design is sensitive to the more conservative rod failure criteria and this should be taken into account when applying the results of that model.

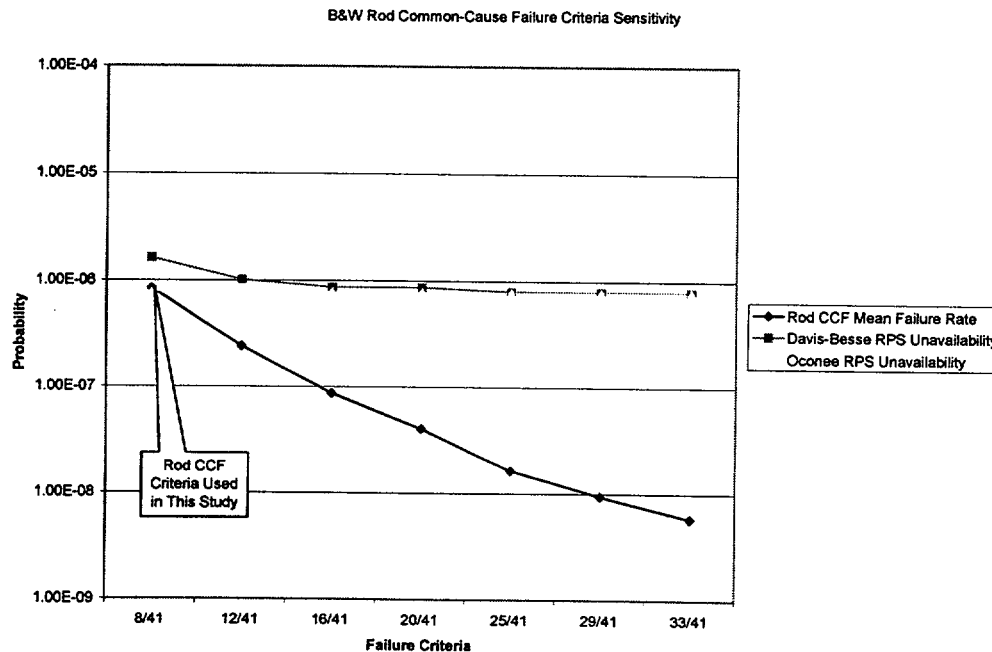


Figure G-3. Sensitivity of ROD events to safety rod failure criterion.

G-3 Diverse Electronic Trip Sensitivity

The diverse electronic trip provides an alternate means of inserting the rods into the reactor utilizing channel trip logic. The diverse electronic trip removes holding power from the rod drives by removing gating power from the SCRs. In the Oconee design, the SCRs provide holding power to the regulating rod groups and in the Davis-Besse design, the SCRs provide holding power to all rod groups. The diverse electronic trip branch of the fault trees was removed and the cutset results recalculated. This section shows the benefit to each design due to the implementation of the diverse electronic trip.

Table G-3 shows the base and modified segment cutset results and an overall percent improvement due to the diverse electronic trip. The Oconee design shows a 71 percent improvement without the operator action and a >99 percent improvement when the operator action to manually trip the reactor is included. When operator action to manually trip the reactor is included, the channel contribution is significantly reduced and the trip breakers become very important without the benefit of the diverse electronic trip.

The Davis-Besse design shows a 31 percent improvement without the operator action and a 46 percent improvement when the operator action to manually trip the reactor is included. When operator action to manually trip the reactor is included, the channel contribution is significantly reduced and the trip breakers become very important without the benefit of the diverse electronic trip.

Table G-3. Diverse electronic trip comparison to base model.

RPS Segment	Unavailability (Point Estimate) with No Credit for Manual Scram by Operator			Unavailability (Point Estimate) with Credit for Manual Scram by Operator		
	Base Model Percent	No Diverse Percent	No Diverse Unavailability	Base Model Percent	No Diverse Percent	No Diverse Unavailability
Oconee RPS Model						
Channel	51.9%	15.1%	4.0E-07	46.5%	0.2%	3.9E-09
Trip Modules	48.0%	14.0%	3.7E-07	42.9%	0.2%	3.6E-09
Trip Breakers/Diverse	0.0%	39.4%	1.1E-06	7.2%	55.4%	1.1E-06
Trip Rods	0.0%	31.5%	8.4E-07	3.3%	44.2%	8.4E-07
Total Oconee RPS	100.0%	100.0%	2.7E-06	100.0%	100.0%	1.9E-06
Davis-Besse RPS Model						
Channel	25.1%	17.4%	4.0E-07	0.5%	0.3%	3.9E-09
Trip Modules	23.0%	16.0%	3.7E-07	0.4%	0.2%	3.5E-09
Trip Breakers/Diverse	0.0%	30.6%	7.1E-07	0.0%	45.6%	7.1E-07
Trip Rods	52.0%	36.1%	8.4E-07	99.1%	53.9%	8.4E-07
Total Davis-Besse RPS	100.0%	100.0%	2.3E-06	100.0%	100.0%	1.6E-06

	Unavailability (Point Estimate) with No Credit for Manual Scram by Operator			Unavailability (Point Estimate) with Credit for Manual Scram by Operator		
	Base Model Unavailability	No Diverse Unavailability	Diverse Trip Improvement	Base Model Unavailability	No Diverse Unavailability	Diverse Trip Improvement
Oconee	7.8E-07	2.7E-06	70.8%	8.7E-09	1.9E-06	99.5%
Davis-Besse	1.6E-06	2.3E-06	30.5%	8.5E-07	1.6E-06	45.6%

Figure G-4 shows the overall point estimate of unavailability comparison between the base model and the model without the diverse electronic trip. Figure G-5 shows a similar distribution, but for the results including operator action. Figure G-5 shows the important difference between the two designs. In the Oconee design, the diverse trip targets a different set of rods (the regulating rods versus the safety rods). In effect, this requires the CCF of the safety rods and the failure of at least one of the regulating rods, decreasing the probability of this cutset to a very small value. The Oconee diverse trip is truly diverse.

Appendix G

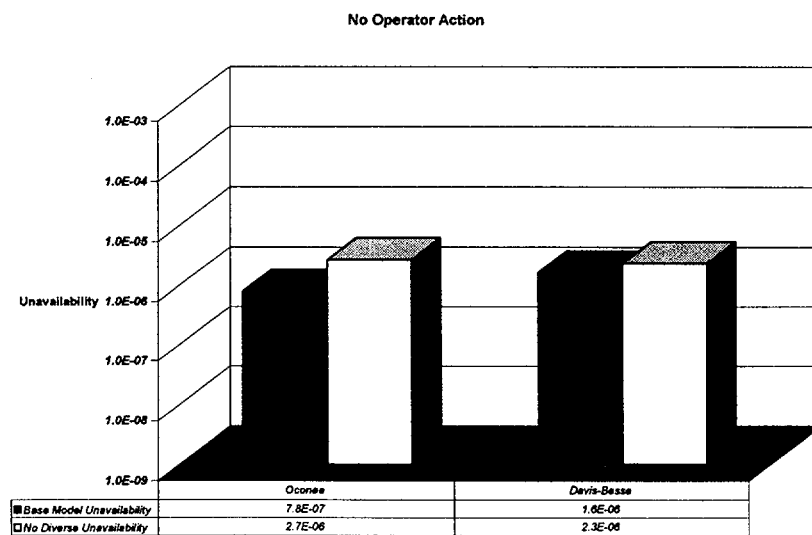


Figure G-4. Diverse electronic trip without operator action.

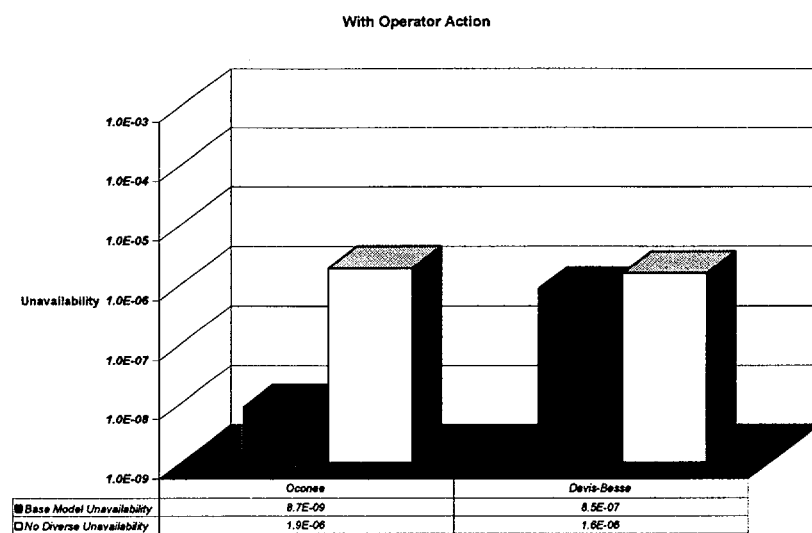
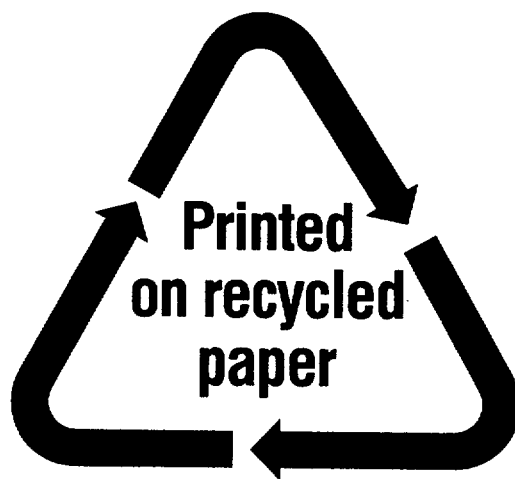


Figure G-5. Diverse electronic trip with operator action.

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